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Front Cover

Nature furnishes the tower, with economy for the city of Seattle, Wash., incident to relocation of a portion of its Skagit River transmission line. Crossarms consisting of 2 8-inch $11^1/_2$-pound channels, latticed back to back, 18 inches apart, support 3 477,000 circular mil A.C.S.R. conductors on 15 foot spacings

Special Articles

A.I.E.E. Papers

—Turn to next page

In This Issue—

CORRECTION—A correction on "Application of Electron Tubes in Industry," which paper appeared in the January 1935 issue of ELECTRICAL ENGINEERING, is published in the "Letters to the Editor" columns of the present issue. The correction concerns electron tube control for resistance welding (*page 1018*).

As this issue goes to press, the Institute's Pacific Coast convention is being held in Seattle, Wash., August 27–30 (and *not* September 27–30, as was stated erroneously on the cover of the August issue). A full report of the convention is scheduled for inclusion in the October issue.

REGISTRATION of engineers was discussed in an address in the August 1935 issue, pages 876–81, and a few additional comments by L. W. W. Morrow were published in that issue, page 899. In the "Letters to the Editor" columns of the present issue, Past-President A. W. Berresford analyzes several important aspects of registration, and urges that engineers, rather than nonengineers, should evolve the standards of registration (*pages 1014–6*).

SECTION officers frequently are confronted with the problem of providing high grade programs for their meetings, and interesting those in attendance sufficiently so that they will participate in discussion. A valuable suggestion for both relieving the work imposed on all concerned by these programs, and increasing their value to members, is contained in a "Letter to the Editor" in this issue (*pages 1016–7*).

THE most accurate methods of drawing and calculating magnetic fields in machinery windings are hard to understand and hard to use; easier methods of calculation are less accurate, and easier graphical methods are harder to analyze. The method of superposition, explained in this issue, is said to fill the gap between the more accurate and the simpler methods (*pages 959–66*).

DURING recent years, one of the most rapidly developing fields open to electrical engineers has been that of industrial electrochemistry. A long series of new products and processes indicates the tremendous activity going on, and a survey of the future shows that many further advances are to be made. Electrochemistry should prove to be one of the most attractive fields for the young engineer (*pages 920–3*).

INVESTIGATIONS of the effect of lightning on power transmission lines have been carried on continuously for several years by one group of investigators. Another paper in the series of reports on these investigations has been prepared. Data on overhead and buried ground wires are given and the amplitude of stroke surge currents is indicated (*pages 934–42*).

PURDUE University, West Lafayette, Ind., will be host for the Great Lakes District meeting of the A.I.E.E., October 24–25, 1935. The technical program, in which students will participate actively, and other features, including inspection trips, a television demonstration, and attendance at a football game, have been announced (*pages 1005–7*).

A MULTIHARMONIC electrostatic audiofrequency generator in which the harmonics are generated by the rotation of a shielded segmented disk adjacent to a stationary plate is described in this issue. Each harmonic is controlled independently, and any 2 or more may be combined to obtain complex wave forms (*pages 950–5*).

REPORTS were presented during the Institute's 1935 summer convention at Ithaca on 2 subjects of interest to the entire membership. One of these is a report of the A.I.E.E. publication committee (*pages 1009–10*). The other is a report on experiences with Section technical committees obtained by the Portland, Ore., Section (*page 1011*).

DELTA connected transformers sometimes are supplied with mid-taps, and loads can be taken off simultaneously at both full and half voltage. Equations and curves have been developed which facilitate the calculation of the maximum permissible load, even though the loading of the different windings is not uniform (*pages 931–4*).

LIGHTNING has been the subject of some 1,300 papers published from 1918 to date by the A.I.E.E. and other organizations. If enough orders are received, a comprehensive reference book containing all of these papers will be issued. Members interested are urged to act promptly (*page 1008 and page 8, advertising section*).

APPLICATION of electric railway motors necessitates the determination of speed-time and current-time curves. An electrograph has been developed in which these curves may be drawn on an oscillograph screen and many laborious calculations avoided (*pages 923–30*).

MEASUREMENT of impulse voltage obtained by noting the breakdown spacing of sphere-gaps may be rendered more dependable by the application of ultraviolet light. The improvement is especially marked for the smaller gaps and lower voltages (*pages 955–8*).

WAVE forms in the d-c side of rectifier circuits may be calculated with considerable accuracy by the application of the Fourier series. A knowledge of these wave forms frequently is desirable, and the accuracy of these calculations has been verified by oscillograms (*pages 977–84*).

LOCI of all voltages and currents in star-star (Y-Y) circuits follow circular paths when any self-impedance in the circuit is varied. A method of determining these loci is presented in this issue (*pages 970–6*).

CATHODE ray oscillograph measurements show that the "firing" time of an igniter type of mercury rectifier tube varies in a statistically systematic manner between successive operations (*pages 942–9*).

IN addition to the national and District prizes for 1934 Institute papers already announced, 2 additional Districts recently announced their awards (*page 1007*).

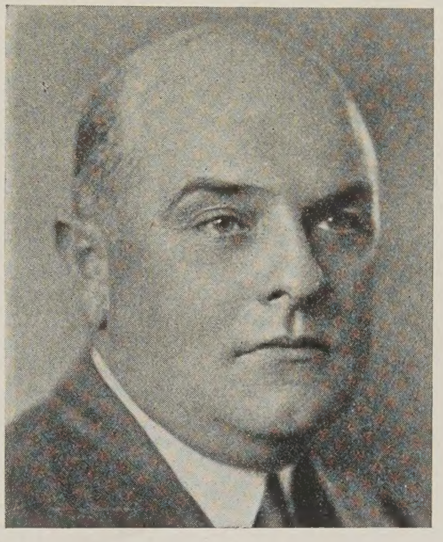
A Message

To the Institute Membership—

TOGETHER we stand at the threshold of another Institute year, looking forward from the point of vantage attained by our officers, directors, committee chairmen, and active members.

A perfect synchronism of the attitudes of our entire membership in a completely co-operative effort toward the continued growth and progress of our Institute would indeed be an ideal accomplishment.

You as individual mechanisms in this great professional society are the vitality of its every aim and purpose and therefore constitute the basis for its success.



Edward Barnard Meyer
A.I.E.E. President 1935–36

Our job today, yours and mine, is to devote every ounce of energy toward building soundly for the future. Our usefulness will not attain a wide scope nor a higher degree of efficiency unless it be expanded along the lines of concurrent effort and co-operative functions.

The joy of personal accomplishment is regarded by some as the greatest of human joys, but unless our perspective be narrow, selfish, and egotistical, we cannot agree to this, preferring to make it secondary to the prime fact that it is most pleasurable to know that oneself has participated in the mutual accomplishment of some worthy effort.

And so it is the co-operative action of the members that so materially aids and guides the board of directors of our Institute in effectively carrying on its work.

The extent of the contribution that can be made by any organization, such as the Institute, is determined by the soundness of its business policies. The furtherance of its aims to promote technological advancement and the best interests of its membership, is predicated upon its ability so to manage its affairs that it may foster uninterruptedly those activities that are consistent with the purposes for which it exists. It is important that its members be qualified technically if advances in the electrical art are to be made, but it is just as important that the members have knowledge of the administrative aspects of the Institute's affairs if they would be equally qualified to promote the well-being of the institution which concerns itself not only with technical matters but also with the improvement of the professional status of those engaged in electrical engineering.

It is a tribute to the profession that our individual engineers through their spirit of helpfulness and the development of mutual understandings have taken a broader view and accepted larger responsibilities not only on current engineering problems but in their applying themselves to the complex problems of modern society. They are cognizant of the growing demand for the application of engineering analysis to the social and economic aspects of our national existence.

The attention of the membership is directed to the problems that are ever before those who constitute the managing bodies of the Institute and to the studious effort that is constantly being made to give the various activities that make up the Institute's life the degree of emphasis that each deserves. It is all the more important that the individual members realize this and give serious thought to possible ways in which they may render assistance to their officers and committee heads.

Over and above all things which may be regarded as specific contributions, however, do we find the question of attitude as the one major responsibility. If the attitude of each member toward the aims and purposes of our society is all that it should be, we may go forward with complete confidence in our ability to deal constructively with any situation that may confront us in the future.

Industrial Electrochemistry Advances

By COLIN G. FINK
Columbia University, New York, N. Y.

Of the many fields of activity open to the young electrical engineer, one of the most fascinating and abundant in opportunities for important developments is that of industrial electrochemistry. A survey of the recent advances which have been made in this field shows the striking wealth of new products and new processes, many of these being of great commercial value. For the future, opportunities for the engineer to make new discoveries are even greater.

AT the time of the harnessing of part of the vast power resources at Niagara Falls 40 years ago, "industrial electrochemistry" was born. Before that time the consumption of electricity in electrochemical processes was relatively insignificant. Today the total installed electric power for electrochemical industries in the United States alone amounts to over 3,000,000 kw—a very significant figure—enough power to light a good-sized tungsten lamp in every home in the whole country. About 1/2 of the power is required by 2 of the electro-chemical products: aluminum metal and calcium carbide.

For many years the major electrochemical plants were segregated at Niagara Falls. Today there are half a dozen important electrochemical centers bebesides a score of smaller installations scattered throughout the United States. Charleston, West Va., boasts of the largest electrolytic alkali plant of the world; at Tacoma, Wash., is one of the large copper refineries of the American Smelting and Refining Company, besides 2 important electrolytic alkali-chlorine plants, one of the Hooker Electrochemical Company and the other of the Pennsylvania Salt Company; another center is Keokuk, Iowa, with its large dam across the Mississippi; then in Montana, at Anaconda and Great Falls, there are the electrolytic zinc and copper plants of the Anaconda Copper Company; and at Massena, N. Y., the major plant of the Aluminum Company. In most of these plants hydroelectric power is used, but steam power is competing successfully in several localities, notably in Tennessee and in California where rates are as low as 3 mills per kilowatt hour. Nevertheless, a number of new hydroelectric power centers are again offering inducements to manufacturers of electrochemical products: at the new Boulder Dam where 500,000 kw will soon be available; at Norris Dam in Tennessee; and at Coulee Dam in the State of Washington.

How is the remarkable development of the electrochemical industry within the past 40 years to be accounted for? Why has the electrical method become the preferred one? The answer is not hard to find. The electrolytic cell turns out products such as aluminum, magnesium, beryllium, and sodium that cannot be produced cheaply in any other way. The electric furnace has given birth to a long series of new products previously unknown: Acheson graphite, carborundum (silicon carbide), alundum, calcium carbide, tungsten metal, stainless steel, "18—8" chrome-nickel steel, ferro-nickel alloys with valuable magnetic properties, new malleable cast irons, etc. Finally, there are a number of chemical and metallurgical products that are made better, more cheaply, and of more uniform quality than by the older, straight chemical methods: thus, for example, all of the copper used in the electrical industries is electrolytic copper—of uniform purity and conductivity. Then there is electrolytic zinc 99.95 per cent pure; phosphorus made in the electric furnace; and electric carbon bisulfide, an important reagent for rayon manufacture.

An address delivered at the annual joint meeting of the Institute's New York (N. Y.) Section and the New York Student Branch convention held in the Engineering Societies Building, New York, N. Y., April 26, 1935. Manuscript submitted April 19, 1935, released for publication June 15, 1935.

New Products and New Processes

Considering only the last 3 or 4 years, many valuable additions to the long list of products and processes of the electrochemical industry may again be recorded. In the electric furnace field, T. F. Baily of Alliance, Ohio, has developed a new furnace for the production of steel direct from ore. The upper part of the furnace resembles a small shaft furnace. Reducing gases (largely carbon monoxide) pass upward through this heated shaft and finely divided iron ore particles pass downward. The particles thus are reduced to metal which drops into the electric furnace forming the base of the shaft. Here, with the aid of the electric arc, the metal droplets are converted into high-grade steel.

The rare metal columbium is now being used in electric furnace practice as an addition to the "18–8" chrome-nickel steel to render it more easily workable. This discovery emanates from the laboratories of Dr. F. M. Becket.

An essential reagent used in the manufacture of artificial silk, rayon, is carbon bisulfide. E. R. Taylor's electric shaft furnace first set up at Penn Yan, New York, 40 years ago, has been improved upon by C. C. Schwegler of the Dow Chemical Company at Midland, Mich. The inlet ports for sulfur vapor are located at or above the level of the electrodes and means are provided for counteracting any tendency on the part of the hot reaction zone to shift, a cause of considerable disturbance in the older types of furnace. The fundamental chemical reaction is relatively simple: Hot charcoal reacts

with sulfur vapor to form carbon bisulfide: $C + 2S = CS_2$.

Another recent development of particular interest to electrical engineers is the introduction of the high frequency furnace into the steel plant. Many tons of the finest alloy steels are now made in the high frequency furnace in direct competition with the arc furnace. Dr. E. F. Northrup of Trenton, N. J., is largely responsible for this development.

In the ceramic industries the firing of the ware is still being carried out in the old-fashioned fuel-fired kiln. However, large-scale tests are now under way substituting the much more efficient electrical means of heating. Here in this country R. E. Gould of Knoxville, Tenn., is in charge of these tests forming part of the program of the Tennessee Valley Authority.

A little over a year ago the Carbide and Carbon Chemicals Corporation received the much coveted McGraw-Hill "award for chemical achievement." This company is largely responsible for the creation of an entirely new chemical industry. The raw materials are coke and limestone. These are fed into a large box-type electric furnace, 3 phase and with 3 electrodes each over 3 feet in diameter. In the zone of the smothered arc, liquid calcium carbide is formed. After tapping this out of the furnace and allowing it to cool and solidify, it is brought into reaction with water to form the well-known acetylene gas used in welding and cutting. From this point on, the new industry develops: with the aid of catalysts, acetylene is interacted with hydrogen to form ethylene and then from this a vast variety of products—alcohols, solvents, gums, etc.—never before equaled in the history of chemistry. The new synthetic "resin" has been trade-named "vinylite." It has been made up into water tumblers, wall panels, phonograph records, floor tiles, translucent light fixtures, door knobs, denture castings, automobile steering wheels, etc.

A relatively small, yet important, new electric furnace product is cemented tungsten carbide originating in Germany but developed on an extensive scale in the United States. This carbide is used as a cutting tool and in hardness is next to diamond, the hardest material available to industry. Practically all of the oil well boring is now carried out by means of tungsten carbide in place of diamond. Furthermore, tungsten carbide tools have found world-wide application in the machine shops. They will cut the hardest steels.

Fused Electrolytes

The typical product of the fused electrolyte cell is aluminum metal; others of industrial importance are magnesium metal, sodium metal, and calcium metal. Recent additions to the commercial list are beryllium and lithium. Beryllium metal has found its chief application among the alloys. About $2^1/_2$ per cent beryllium added to copper produces an alloy that is highly corrosion-resistant, relatively hard—like tempered spring steel—nonmagnetic and nonsparking. This last property is particularly important in plants where inflammable vapors occur and where the spark of an ordinary steel tool has often caused a serious explosion. All kinds of beryllium-copper tools, chisels, scrapers, pry bars, hammers, etc., are now on the market and many thousands of beryllium-copper springs are in service today giving a remarkable, low-fatigue performance. Contact clips, pins, and plugs for electrical appliances constitute another important application of this beryllium-copper alloy. In comparison with the older bronzes, the life of these clips and plugs has been increased 10-fold.

In nature beryllium occurs widely distributed in the earth's crust. Beryl, a beryllium aluminum silicate, is the chief mineral. A relatively simple method of separating the beryllium from the other constituents of the ore has been worked out lately and is giving very satisfactory results.

Lithium metal, the other new fused salt cell product, has likewise found its chief application in the alloy field. A few tenths of one per cent of lithium, together with small percentages of other elements, develops steel-like properties in aluminum. The lithium-calcium alloy is a valuable scavenger. Upon adding it to molten steel or other metal it will combine with practically all undesirable impurities.

Aluminum metal has decked itself in a new coat. Anodically-treated aluminum has resulted in a wide variety of new products, many of which are highly colored and look very attractive, especially to the modern housewife. Aluminum mirrors have replaced silver mirrors for telescopes and have been found to be superior to these—an epochal event.

The electrical engineer has become very much interested within the last 2 or 3 years in one of the older products of the fused salt cell, namely, sodium metal. This is used in the new highway or sodium arc lamp, in itself a pretty illustration of applied electrochemistry. Sodium arc lamps have been made before, 30 years ago, but they would not start automatically as the new ones do. The present development has incorporated the hot cathode of the radio tube and the gas of the neon sign. Upon closing the circuit of the new sodium arc lamp the neon gas is ionized, becomes conductive and hot, causing the sodium metal to be vaporized and ionized, and thereupon the sodium arc is established. This 3 step starting of the arc results in the familiar "sun rise" effect in these new, highly efficient lamps.

Another new application of sodium metal of interest to engineers is based upon its high thermal conductivity. Hollow steel sections are filled with sodium metal and used for various machine parts. Thus the valves of aeroplane motors are "sodium" cooled.

Barium metal, which has been made by the fused salt process for many years, has also found important, if not the most important, application in the electrical field. The valuable function of barium as an electron emitter and getter in vacuum tubes is well known to most readers. Recently D. W. Randolph of the A. C. Spark Plug Company has reported on a nickel-barium alloy used as spark terminal. A uniform and quietly operating spark is obtained. M. A. Baernstein has found that the introduction of

barium compounds into the electric furnace arc results in a much more uniform and smoother performance of the arc.

Aqueous Electrolytes

Of greatest scientific importance was the discovery of heavy hydrogen, or "deuterium," by Dr. H. C. Urey and associates at Columbia University. This newcomer is a product of the electrolysis of water between nickel electrodes.

In the electrolytic alkali-chlorine industry an epoch-making application of chlorine gas is charging it into sea water and liberating tons of bromine—an important reagent in photography and in making "antiknock" gasoline. The large bromine plant is situated at Cape Fear, N. C.

In the electrolytic copper industry a noteworthy new product is the paper-thin copper sheet produced in endless lengths on a large revolving lead drum that serves as cathode. This was brought to commercial perfection by Shakespear, Levi and others of the Anaconda Copper Company. Very recently the thin copper sheet has been applied to paper and serves as an attractive wrapper for a wide variety of products.

For years the industry has been looking for a metal coating which would be resistant to the strongest of acids, muriatic, and at the same time easily applied. A short time ago this problem was tackled at Columbia University by a group including the author, and now with the assistance of Mr. Deren it has been possible to locate and develop the desired metal coating. It has been found that rhenium metal can be electrodeposited on copper, brass, and steel, and in that way protect them against muriatic acid attack. Aside from industrial applications rhenium plate is of special interest to jewelry manufacturers. Wrist bands which are rhenium-plated resist the attack of the acids in perspiration. Chromium, rhodium and even silver are attacked by perspiration whereas rhenium is not. Rhenium plate is remarkably free from pin holes, does not tarnish nor smudge. The present sources of rhenium metal are the slimes of one of the large electrolytic copper refineries. These copper cell slimes have given rise to a number of industries. Thus selenium, an essential metal in many of our modern photoelectric devices, is extracted from these slimes. Selenium and its sister metal, tellurium, are now being regularly recovered at electrolytic copper and electrolytic nickel plants. Tellurium is an important reagent in the electrolytic zinc industry.

Several laboratories have devoted considerable effort to the electrodeposition of alloys. The Bell Telephone Laboratories have electrodeposited magnetic alloys composed of iron, nickel, and cobalt. At the University of Minnesota, C. L. Faust and G. H. Montillon have developed a process for the deposition of nickel brasses. Brass as such has been commercially deposited on steel for the last 15 years. At Columbia University, the author and others have been depositing a silver-white corrosion-resistant alloy of cobalt and nickel; also a highly acid-resistant alloy of silver and lead, and another of tungsten and palladium. This field is a most fascinating one and offers great possibilities. The mechanical preparation of thin alloy sheets is often very difficult and tedious, whereas the electrodeposition of such sheets is usually relatively simple.

Electrochemistry of Gases

Of all branches of electrochemistry, that concerned with the discharge of electricity through gases is the most fascinating. However, due to the greater ease in handling solids and solutions, investigators usually avoid this branch of the science. From a practical point of view a number of circumstances have in recent years contributed toward a better acquaintance on the part of the engineer with gas reactions, gas transportation, gas recovery and generation, etc. Thus the use of gases in welding and cutting, gases in warfare, neon and other gases in electric signs, ozone generators, Cottrell precipitators, gas arcs, etc., have all helped to bring about a decided change in attitude on the part of the engineer. From an industrial point of view the recent developments in the sodium vapor and high-pressure mercury-vapor arcs deserve special mention. Important, too, are the researches of Dr. S. C. Lind at the University of Minnesota on various gas reactions initiated by radium emanations, and the researches of the Fixed Nitrogen Laboratory at Washington, D. C., under the direction of Dr. F. G. Cottrell on electrical methods of synthesizing nitric oxide. Electrical engineers will recall that in the corona discharge nitrogen is more readily ionized than oxygen—quite contrary to our early suppositions.

Many Unsolved Problems in Electrochemistry

Young students desirous of taking up a research problem often feel that "everything has been solved." This is far from the truth. Every new product or new process gives rise to a dozen new problems. The discovery of high frequency induction melting of steel and the appreciation of its commercial possibilities happened years before the first large furnace was in successful operation in the steel plant, and the delay was largely due to the many problems that had to be solved before the basic discovery was adaptable commercially.

Opportunities are greater than ever before and the possible new discoveries are unlimited in every branch of electrochemistry. An electric furnace is needed that will easily and efficiently convert ores into finished metal products; a new process is needed for the production of aluminum metal, one that is much simpler and cheaper than the present one; further development of the photovoltaic cell is needed so that it will readily convert large blocks of sun power into electric power; strong, low density alloys are needed that have a fatigue resistance equal to that of steel; a simple means of electrically controlling and directing rainfall—keeping it out of the cities—must be found; most urgently, there is needed a simple but efficient method of protecting steel products and steel structures against corrosion and thus save many millions of dollars now lost;

an electric source of illumination must be found suitable to human eyes, that will operate at 90 per cent and better in efficiency instead of less than 10 per cent, as at present; efforts are being made to find an electric heating unit that will operate a thousand hours or more in air at temperatures of 2,000 degrees centigrade (3,600 degrees Fahrenheit) or above; a simple process of producing large ingots of malleable titanium metal, one of the most prevalent constituents of the earth's crust (6,000 times as abundant as lead) must be found; the application of electric currents in the stimulation of the growth of living cells and the formation of many important organic compounds should be systematically investigated; dielectrics free from the short-comings of the many in use today must be found and developed; hundreds of new products are needed which were difficult or impossible to discover during the countless ages of the past with mechanical skill alone, but today readily possible through the combined power of electricity and chemistry. Truly the young electrical engineer looking for "worlds to conquer" will do well to survey the vast but little-explored domains of electrochemistry.

The Speed-Time Electrograph

The determination of speed-time curves and current-time curves as related to the duty cycles of electric railway motors may be greatly simplified by the use of an electrograph which has been developed, thereby making unnecessary the usual calculations which require considerable time. In this machine, the curves are drawn on an oscillograph screen. The equipment, which can also be used to obtain other characteristics, depends for its operation upon the similarity of equations in the mechanics of train movement and those involved in the electrograph circuit.

By
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ASSOCIATE A.I.E.E.

New York University
New York, N. Y.

IN electrical railway engineering work it is sometimes necessary to calculate and plot speed-time curves for scheduling purposes, current-time curves in estimating power requirements, speed-distance curves in connection with signal placing and current-squared-time curves in the selection of motors to perform a certain duty cycle. The usual procedure in plotting such curves is to "solve" the differential equations involving empirical quantities by a graphical point to point method. The appendix to this paper shows a sample set of such calculations.

While these calculations are not particularly difficult, the time involved is considerable and the accuracy depends to a large extent upon the judgment and care with which they are performed. In many cases, to insure reasonable accuracy, the curves must be checked, a task which is none too easy even with such standardized methods as are usually employed. The natural result is that these basic curves for electrical railway work are drawn only when absolutely essential, due to the time necessary and the consequent high cost of such calculations.

With the expectation that the development of any rapid electrical means of performing these calculations might increase their use an experimental "speed-time electrograph" has been built at New York University. The operation of this machine depends upon the similarity of the fundamental differential equations in the mechanics of train movement and the electrical equations involved in the speed-time electrograph circuit. The machine plots the speed-time curves for certain experimental runs up to the point selected by the operator and the distance traversed may be read directly. (Standard meters require a multiplying factor.) A current-time curve per motor may be plotted simultaneously and kilowatt-hours and amperes-squared-seconds read directly.

The speed-time and current-time curves are drawn on an oscillograph screen in the usual manner and may be preserved, if necessary, by photographing them. Since the usual results desired are obtained directly, there appears to be no reason for preserving these curves except where actual records of the train speed or motor current at certain times is desired or for checking work at a later date.

Figures 1 and 2 show 2 views of the experimental speed-time electrograph as set up in the laboratory.

Relation of the Fundamental Electrical and Mechanical Equations

Since the general similarity of electrical and mechanical equations and quantities has already been discussed in several papers[1, 2, 3] it seems unnecessary to more than briefly outline the particular conditions

A paper recommended for publication by the A.I.E.E. committee on transportation. Manuscript submitted January 8, 1935; released for publication March 4, 1935.

1. For all numbered references see list at end of paper.

which must be met in the speed-time electrograph.

In order to plot electrically both the speed of the train and the current per motor, 2 separate circuits are necessary. The current whose magnitude represents the speed of the train may be termed the "speed-current," while the small current representing actual current per motor will be called the "I-current."

From the mechanics of train movement[5,6]

$$T = 100W\frac{dV}{dt} + R + C \pm G \qquad (1)$$

where

T = tractive effort per motor in pounds
W = total weight per motor in tons
$\frac{dV}{dt}$ = acceleration in miles per hour per second
R = train resistance per motor in pounds. This resistance will be a function of the speed of the train for any particular train
C = curve resistance per motor in pounds which depends, for any particular train, upon the degree of curvature of the track
G = grade resistance per motor in pounds, which for any particular train, depends upon the per cent grade. A plus sign precedes an up-grade while a minus sign precedes a down-grade

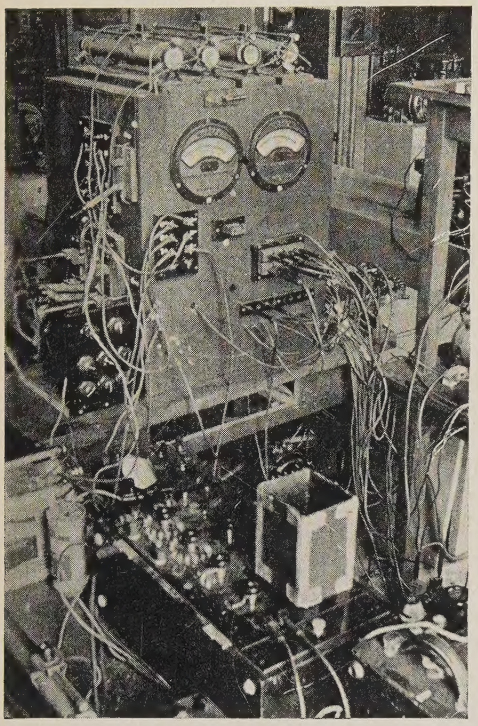
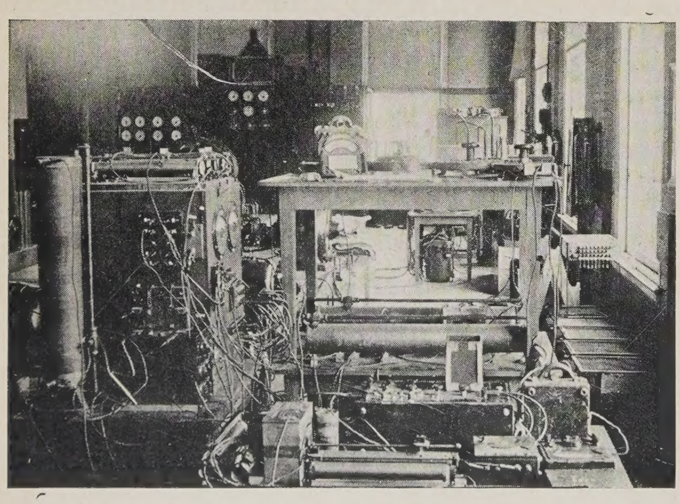


Fig. 1 (left). Front view of the experimental speed-time electrograph

Fig. 2 (below). Another view of the speed-time electrograph, taken from the side



The equivalent series circuit electrical equation is

$$E_T = L\frac{di}{dt'} + E_r + E_c \pm E_g \qquad (2)$$

where E denotes a voltage rise and the subscripts indicate the items which are equivalent to those of equation 1. It will be noticed that E_r must vary with the current while E_c and E_g are fixed values for any particular condition of gradient and track curvature.

Since the speed V in miles per hour may be multiplied by a constant to obtain i, the speed-current in amperes

$$VK_v = i$$

also

$$TK_T = E_T$$

since tractive effort corresponds to electromotive force. t, the actual train time, is related to t', the electrical circuit time, in the same fashion, or

$$tK_t = t'$$

In order to have a repeating electrical circuit phenomena which may be traced on the oscillograph screen, it is necessary to have a stationary commutator the segments of which may be connected to one another and to the various circuits. A rotating brush changes the electrical connections in the same sequence during every revolution. The time for one revolution will determine the total electrical graph cycle time so that it is necessary to select a convenient maximum time for an actual train run so that

$$K_t = \frac{\text{Total electrical graph cycle time in seconds}}{\text{Total maximum time for a train run in seconds}}$$

If the graph cycle time is $^1/_{30}$ second, as it is for a commutator speed of 1,800 revolutions per minute, and the maximum actual time for a train run is 10 minutes, K_t becomes $^1/_{18,000}$.

The value of the inductance L corresponding to a certain train weight per motor may be calculated since

$$100W\frac{dV}{dt}K_T = L\frac{di}{dt'}$$

$$(dV)(K_v) = di \text{ and } dt(K_t) = dt'$$

so

$$\frac{(100W)(K_T)(K_t)}{K_v} = L \text{ in henries} \qquad (3)$$

It may be pointed out that equation 3 allows considerable variation in the selection of the total screen time in terms of actual time since this may be changed to any period desired within the upper limit imposed by the maxium inductance available.

Elementary Theoretical Circuit

Figure 3 shows the usual speed-amperes and tractive effort-amperes curves for a 50-horsepower d-c traction motor. If these curves are used to plot a speed-tractive effort curve this may be plotted as shown in figure 4, the solid line marked "tractive

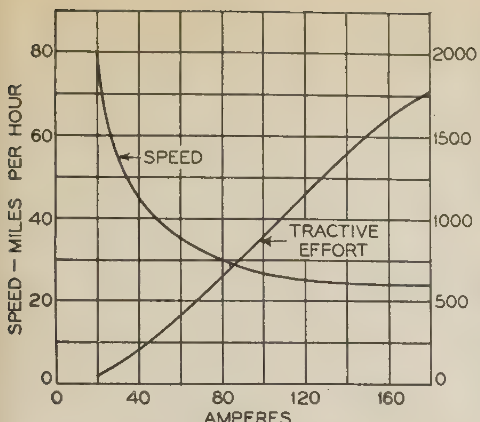


Fig. 3. Motor performance curves

D-C railway motor; hourly rating: 50 horsepower, 600 volts, 72 amperes, 900 rpm

Continuous capacity (85 degrees centigrade rise by resistance on stand test): 47 amperes on 300 volts; 51 amperes on 450 volts; 55 amperes on 600 volts

26 inch wheels; 20:47 gear ratio

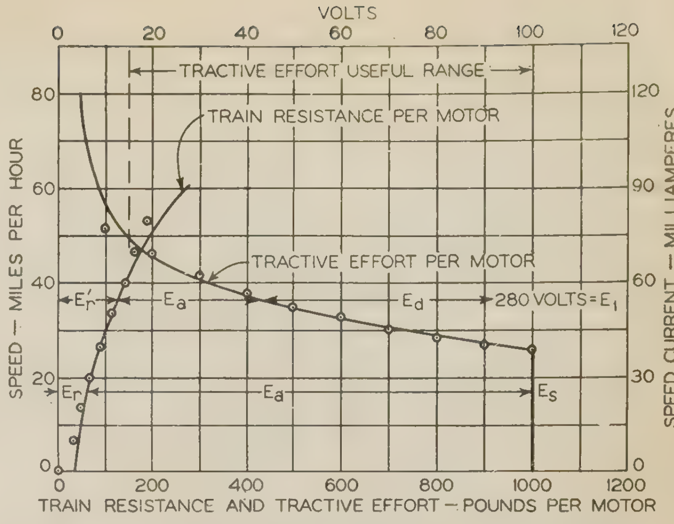


Fig. 4. Speed-resistance and speed-tractive effort curves

Solid lines show values plotted from figure 3
Plotted points show corresponding electrical values obtained

effort per motor." The curve for "train resistance per motor" as calculated from the Davis formula[4] may also be plotted on the same figure. Since the speed-current is electrically equivalent to the train speed in miles per hour, and tractive effort or train resistance may also be plotted in equivalent volts, both sets of scales may be shown on the same diagram.

The elementary theoretical circuit diagram of the speed-current circuit is shown in figure 5. The circuit set up in this figure illustrates the theoretical circuit for the main wiring diagram, figure 7, and the sample results given later in the paper.

In order to duplicate electrically the control of the train, it is necessary to have 4 "control" circuits. In figure 5 these are lettered S, T, C, and B to signify start, run, coast, and brake, respectively. In each case the control circuit determines the value of E_T in equation 2 just as the control equipment on the train regulates the value of T in equation 1.

The circuits below the commutator segments P, V, W, and X are "grade" circuits. There must be as many grade circuits as there are different conditions of grade and curvature for a particular train run. Since the curve resistance voltage E_c may be set up as an equivalent grade voltage E_g, the 2 terms might have been combined in equation 2.

In figure 5 the inertia of the train is represented by the inductance L. As mechanical train resistance can only be represented by a voltage electrically, it may be considered that $-E_r$ (or $-E_r'$) is practically the voltage drop through a vacuum tube, the characteristic of which has been adjusted to approximate the train resistance curve of figure 4.

The area of the speed-current wave against time is equivalent to distance, and since this area can only be obtained by the variation of control and grade circuits in the correct sequence and at the proper instants, theoretically an infinite number of commutator segments would be necessary.

In starting an electric train the function of the electrical control equipment is to hold the starting current per motor practically constant during the starting period, which means that the tractive effort is constant during this time. (See figure 3.) In figure 4 this constant tractive effort (of 1,000 pounds) is marked E_s. This condition continues until the train has reached the speed at which this constant value of tractive effort intersects the "tractive effort per motor" curve. In equation 1 this is equivalent to making T a constant, while in equation 2, E_T is a constant E_s.

In figure 5, the brush travels from left to right first making contact with the starting segment and completing the circuit $OPSMRO$. In this case the start is made on level tangent track, no grade voltage is necessary, and equation 2 becomes

$$E_s = L\frac{di}{dt'} + E_r = E_a + E_r \tag{4}$$

which is shown graphically in figure 4. As the speed-current increases the electromotive force available to overcome the back electromotive force of the inductance $\left(-L\frac{di}{dt'} = -E_a\right)$ becomes less as more voltage drop occurs through the vacuum tube "train resistance."

When the train has reached the lowest speed at which all motors may be connected for full line voltage the tractive effort becomes a function of the speed, as shown by figure 4, "tractive effort per motor." Returning to figure 5; as the brush continues to the right, circuit $OPTNMRO$ is completed just before the starting circuit is opened thus keeping the series speed-current circuit intact. In this circuit E_1 is a constant electromotive force, while E_d is the difference in potential across a vacuum tube circuit. The voltage equation is

$$E_1 = E_d + E_a' + E_r' \tag{5}$$

where E_a' indicates $L\frac{di}{dt'}$. The equation is shown graphically in figure 4. Equation 5 may be rewritten

$$E_1 - E_d = E_a' + E_r'$$

which means that the electromotive force available for tractive effort is $E_1 - E_d = E_T$ for equation 2. For this type of curve E_T may be easily adjusted to fit the tractive-effort curve. When E_a' has become

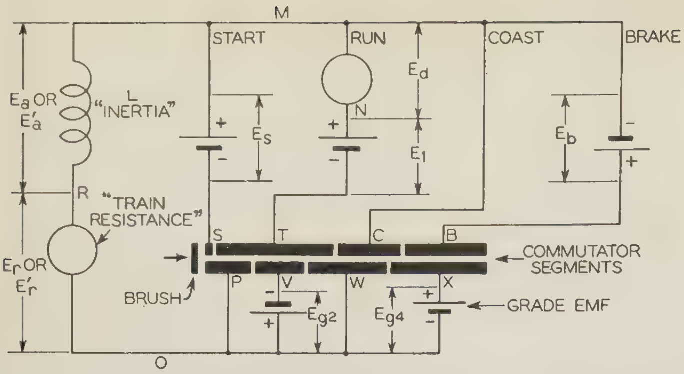


Fig. 5. Elementary schematic diagram of speed-current circuit

Set up for conditions of example given

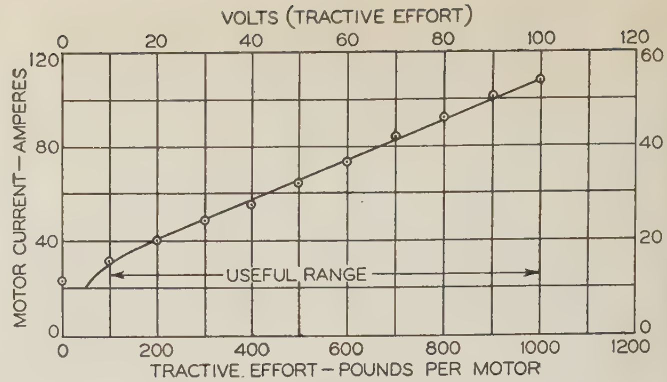


Fig. 6. Motor current-tractive effort curve and I-current, volts equivalent

Solid lines show plotted values from figure 3
Plotted points show corresponding electrical values obtained

zero, $E_T = E_r'$ which corresponds to the balancing speed of the train.

As the brush proceeds, it completes in succession circuits *OVTNMRO*, and *OWTNMRO*. In the former an "up-grade" voltage, E_{g2} is inserted and equation 5 becomes

$$E_1 - E_d = E_T = E_a' + E_r' + E_{g2} \tag{5a}$$

The latter circuit is a repetition of equation 5 since the "train" is again on level tangent track.

At this point it may be assumed that the power is cut off and the train is to coast. (Level tangent track.) In the mechanical equation 1 this corresponds to making T, G, and C zero and the equivalent electrical equation becomes

$$L\frac{di}{dt'} + E_r' = 0 \tag{6}$$

This is accomplished electrically as the brush passes to circuit *OWCMRO* and disconnects the motor running circuit. The inductance takes the place of the inertia in the mechanical system and the speed-current starts to decrease. $\left(L\frac{di}{dt'} \text{ is negative.}\right)$

As the brush connects segment X, figure 5, circuit *OXCMRO* comes into play inserting a "down-grade" voltage, E_{g4} and equation 6 becomes

$$L\frac{di}{dt'} + E_r - E_{g4} = 0 \tag{6a}$$

and the speed-current increases as the "train" coasts downhill.

If the brakes are applied as the train coasts downhill the mechanical equation is

$$-B = 100\,W\frac{dV}{dt} + R - G \tag{7}$$

where $-B$ (braking force) takes the place of T in equation 1. Since this is usually assumed to be a constant for speed-time curves the electrical equation may be shown as

$$-E_b = L\frac{di}{dt'} + E_r - E_{g4} \tag{8}$$

which is the equation for the braking circuit *OXBMRO*. The speed-current goes to zero very quickly with this connection. It is interesting to note that if it were not for the valve action of the "train resistance" vacuum tube the "train" would "roll backward" if stopped on an "up-grade."

As the brush is revolving at a speed of, say, 1,800 rpm, this sequence of circuits is repeated continuously so that an oscillograph element placed in the circuit of figure 5 at point R draws the speed-time curve on the screen of the oscillograph. This curve is stationary if the brush and oscillograph mechanism are in synchronism. A magnetic type milliameter at the same point reads the average value of the current wave per brush cycle, which is proportional to distance.

Main Wiring Diagram

Figure 7 shows the speed-current circuit on the left and the I-current circuit on the right. The commutator is divided into an inside ring of "grade segments" and an outside ring of "control segments," which may be connected to the appropriate grade potentiometer voltages through the grade plugs or to the control circuits, respectively.

The circuit lettering for figure 7 corresponds to that of figure 5 so that the explanations for circuit functions apply directly to figure 7. In operation, all of the switches are, of course, closed, except the "test switch" and the switch protecting the distance milliameter and speed-current oscillograph element. Circuits necessary to eliminate commutator ripple are not shown. Voltmeters across all of the generators and voltmeters to set grade and control voltages have also been omitted to simplify the diagram. It is evident that each vacuum tube or group of vacuum tubes must be supplied with filament current from a separate transformer winding.

The voltage E_d of figure 5 may be adjusted in figure 7 by means of the grid voltages of the tubes, the resistances in series with the tubes, and by means of the resistance between points N and M. The tractive effort curve of figure 4 can be approximated to almost any accuracy desired if a sufficient number of tubes are used.

The function of the gas-filled grid-controlled "safety tube" in the circuit is to take the inductive "kick" as the speed-current is broken during the time the speed-time curve is being set up. This device

holds the voltage across the inductance to a low value and at the same time practically short-circuits the inductance so that the oscillograph speed-current goes to zero very rapidly, almost eliminating any "distance" error due to a continuation of current (by arcing at the brush) through the main circuit by inductive action. In this case the safety tube was set to operate at 100 volts reverse voltage, considerably higher than the voltage induced during the braking portion of the speed-time curve.

The train resistance voltage E_r (figure 4) may be approximated since the train resistance in pounds is given empirically[4] by an expression of the form

$$R = K_I + K_{II}V + K_{III}V^2$$

where V is speed in miles per hour and K_I, K_{II}, and K_{III} are constants. Electrically this becomes

$$E_r = E_p + ir + i^2r'$$

E_p may be set on the grade potentiometer, r may be adjusted with the resistance R in figure 7 and must include the resistance of the air core inductance, while the term i^2r' may be approximated with one or more vacuum tubes.

I-Current Circuit

On the right hand side of figure 7 the *I*-current circuit is shown. This circuit is controlled by the tractive effort voltage which is applied between the point M and the brush, acting through the 250,000 ohm circuit which is connected to the grid of the tube I_1 through the bias battery. The object in having the 2 vacuum tubes in series is to provide the proper characteristic (as shown in figure 6) between tractive effort voltage and *I*-current, with a negative grid control. This arrangement allows both tubes to operate on rated filament voltage. The curve of figure 6 could probably have been approximated much more closely by using more vacuum tubes.

In this experimental machine an "*I*-current plugging circuit" is necessary to reduce the *I*-current to zero when point M is not directly connected to point O by control circuits. In this case the "plugging circuit" sends a current through the 250,000 ohm grid control circuit for tube I_1 which makes the grid of this tube sufficiently negative to cut off all plate current.

It seems evident that since the *I*-current is determined by the tractive effort voltage at any instant, an oscillograph element placed in the circuit will draw the current-time curve. A magnetic type milliameter reads the average area, from which kilowatt-hours may be determined, and a thermal type instrument in the same circuit reads the root mean square value of current from which amperes-squared-seconds may be obtained.

Results for a Particular Test Run

The present machine is purely experimental since the commutator is divided into a relatively small number of segments providing a combination of test runs for experimental work. For practical calculations such a machine should have 300 sets of segments, thus allowing control and grade changes every 2 seconds for a 10 minute screen, or every second for a 5 minute screen.

The test run outlined in table I is for a light interurban car having 4 50 horsepower d-c motors. All figures shown in table I are summations from the starting point. For instance, the profile is shown by the figures opposite "Grade" in the table; the car runs from the starting point a distance of 4,500 feet on level tangent track, at which point it starts to climb a 1.373 per cent grade which extends to 10,267 feet from the starting point, etc.

The weight per motor is 6.188 tons. For the speed-current 1.5 milliamperes are equivalent to 1 mile per hour giving a value for K_v of 0.0015 while 1 volt is equivalent to 10 pounds per motor so that $K_T = 0.1$ giving a value of 2.29 henries, for the inductance to represent inertia with a commutator speed of 1,800 rpm. (Equation 3.)

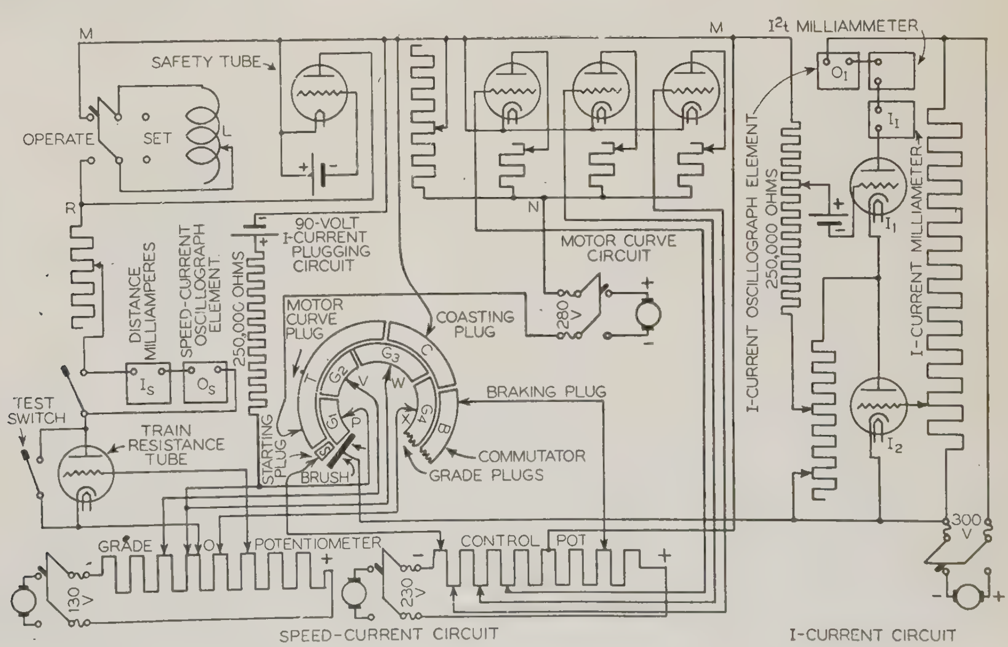


Fig. 7. Main wiring diagram

Set up for conditions of example given

Table I—Test Run

Starting current per motor, 108 amperes, which gives a normal acceleration rate of 1.48 miles per hour per second. (T = 1,000 pounds or E_s = 100 volts.) Normal braking rate 1.78 miles per hour per second. (B = 1,040 pounds or E_b = 104 volts.)

Step	A	B	C	D	E	F	G
Grade—volts	0	0	17 Up	0	0	19 Dn	19 Dn
Grade—per cent	0	0	1.373 Up	0	0	1.535 Dn	1.535 Dn
Distance—ma	0.565	7.67	17.5	23.4	31.5	33.6	34.1
Feet from start	332	4,500	10,267	13,729	18,481	19,713	20,006
I-current, ma	1.58			10.3			
Kw-hr at 600 v	0.316*			2.06*			
I^2t—ma	9.2			17.2			
(Amp.)^2 (Sec.)	203,136			709,056			
Time—ms	0.968	4.8	10.2	13.2	18.5	20.0	21.1
Time—seconds	17.4	86.4	183.6	237.6	333.0	360.0	379.8

* See text.

(Per cent grade) (12.38) = grade volts
(Distance milliamperes) (586.7) = distance in feet
(I-current milliamperes) (0.2) = kilowatt-hours at 600 volts
(I^2t milliamperes)^2 (2,400) = (amperes)^2 (seconds)
(Milliseconds) (18) = seconds

Root mean square current for the run $= \sqrt{\dfrac{709{,}056}{379.8}} = 43.2$ amperes while the continuous rating is 55 amperes at 600 volts. Actual kilowatt-hours for the car on this run = (2.06 − 0.316/4)4 = 7.924.

A one per cent grade is equivalent to

$$(20)(W)K_T = (20)(6.188)(0.1) = 12.38 \text{ volts}$$

To convert distance milliamperes to feet from the starting point:

$$\text{Distance in feet} = \left(\frac{\text{amperes}}{K_v}\right)\left(\frac{t}{3{,}600}\right)(5{,}280)$$
$$= \frac{(\text{distance milliamperes})\ (600)\ (5{,}280)}{(1.5)\ (3{,}600)}$$
$$= (\text{distance milliamperes})\ (586.7)$$

where t is the maximum train run in seconds.

To compute kilowatt-hours at 600 volts for the relation of I-current to actual current shown in figure 6 (1 milliampere I-current is equivalent to 2 amperes motor current):

$$\text{Kilowatt-hours} = \frac{(I\text{-current in milliamperes})\ (2)\ (t)\ (600)}{(3{,}600)\ (1{,}000)}$$
$$= \frac{(I\text{-current in milliamperes})\ (2)\ (600)\ (600)}{(3{,}600)\ (1{,}000)}$$
$$= (0.2)\ (I\text{-current in milliamperes})$$

(Ampere)^2 (seconds) may be obtained from the I^2t thermal type milliammeter I-current reading since,

$$(\text{amperes})^2\ (\text{seconds}) = (I^2t \text{ reading in milliamperes})^2\ (2)^2\ (t)$$
$$= (I^2t \text{ reading in milliamperes})^2\ (2{,}400)$$

where I^2t simply indicates the particular meter read and has no mathematical significance.

All of the curves and diagrams given herewith refer directly to this particular test run. Every step indicated by table I is shown graphically by an oscillogram in figure 8, with the same letter following the figure number as in table I.

To set up the speed-time curve for the profile of table I the starting plug of figure 7 is inserted after adjusting E_s to 100 volts, corresponding to 1,000 pounds tractive effort at 108 amperes in figure 3. The zero grade plug G_1 is also inserted and the time for the starting segment adjusted until the speed-current oscillograph screen shows that the motor curve running speed has been attained (26 miles per hour). The oscillograph screen for this starting step is shown by figure 8A. The distance milliameter now reads 0.565 milliamperes showing that the car has traveled 332 feet. (See table I.)

The I-current oscillograph trace for this starting period is shown by figure 8H and the I-current milliampere meter reads 1.58 milliamperes which means 0.316 kilowatt-hours at 600 volts. The I^2t milliampere meter reads 9.2 milliamperes, which becomes 203,136 (ampere)^2 (seconds) as shown in table I, column A.

The motor curve plug is now inserted and segments added until the distance milliamperes become 7.67 corresponding to 4,500 feet. (See figure 8B.)

The G_2, 17 volts "up-grade" plug is inserted and

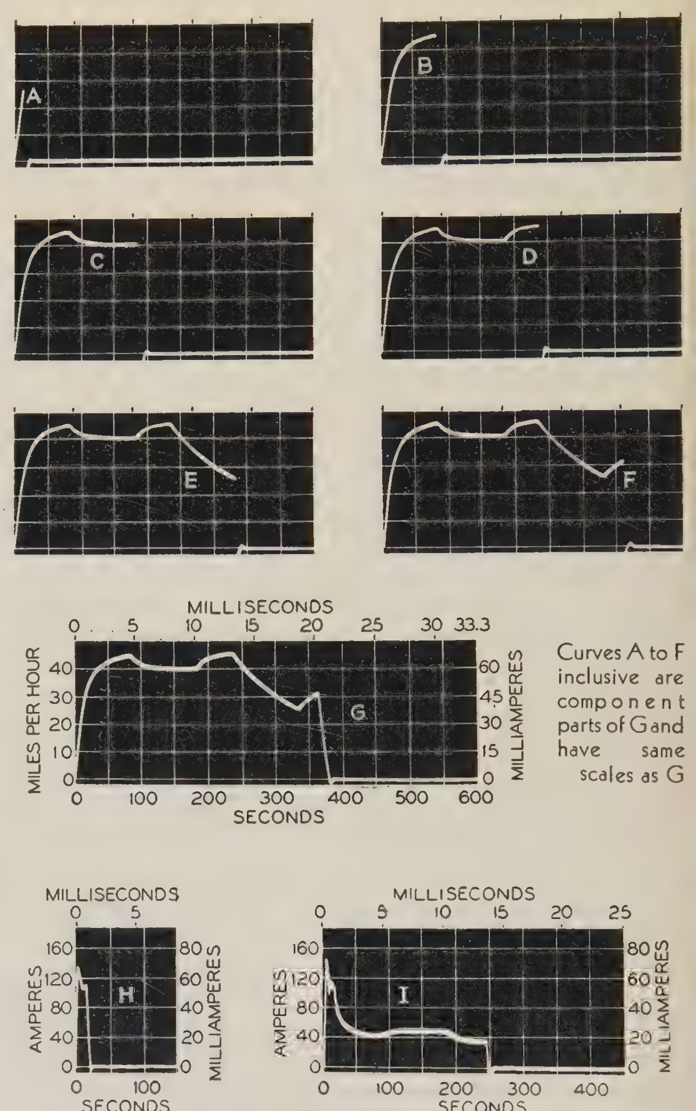


Fig. 8. Oscillograph record showing speed-time and current-time curves

A—Level starting step
B—Level motor curve running step
C—Up-grade motor curve running step
D—Level motor curve running step
E—Level coasting step
F—Down-grade coasting step
G—Down-grade braking step and complete speed-time curve
H—Current for starting step (8A)
I—Current for starting and running (8D)

more segments added until 17.5 milliamperes is read as "distance" and the screen shows the speed-time curve of figure 8*C*. Figure 8*D* shows the complete power running speed-time curve and figure 8*I* the *I*-current oscillograph trace of the current for one motor during the "power on" time.

The curve is completed as indicated by the steps shown by figure 8*E* and figure 8*F* and the complete speed-time curve as figure 8*G* which shows the total available screen time, for the test machine, of 10 minutes.

The scales shown on the oscillograms were added after printing the films to show the relation between the mechanical and electrical systems.

The root-mean-square current per motor for the run, as calculated under table I, is 43.2 amperes as compared with the continuous rating of 55 amperes at 600 volts.

Since the starting period kilowatt-hours in table I (column *A*) are for 600 volts and the motors are in series for approximately $^1/_2$ the starting period, this figure must be adjusted to 75 per cent of its present value or 0.237. As the total kilowatt-hours at 600 volts, column *D*, are also high by the same amount this must be reduced as shown under table I so that for 4 motors the total energy for the run is 7.924 kilowatt-hours.

Accuracy of the Results, and Conclusion

Table II indicates the results obtained with the electrograph and 2 sets of calculated values for this particular run.

Check *A* (see appendix for complete check *A*) is from a speed-time curve constructed in the usual manner using the maximum starting train resistance for straight line acceleration, while check *B* uses average speed resistance for starting.

Since no 2 calculated curves are exactly the same if the work is performed by 2 persons who are not collaborating, the "accuracy" of the machine seems rather difficult to determine. In general, however, the speed-time curves which have been obtained seem to be at least as accurate as the usual graphical solutions.

In table II the energy checks are almost identical with the electrograph results and the ampere-squared-seconds check rather closely with the exception of the check *B* value for column *D* which differs by 3.8 per cent.

Table II—Calculated Checks on Electrograph Results

Step	A	B	C	D	E	F	G
Time—Seconds							
Electrograph	17.4	86.4	183.6	237.6	333.0	360.0	379.8
Calc. check *A*	17.6	88.0	184.4	238.0	331.0	360.0	381.1
Calc. check *B*	17.4*	86.5	181.5	235.0	332.0	356.0	378.0
Energy—Kilowatt-Hours at 600 Volts**							
Electrograph	0.316			2.060			
Calc. check *A*	0.317			2.044			
Calc. check *B*	0.314			2.060			
Amperes-Squared-Seconds							
Electrograph	203,136			709,056			
Calc. check *A*	205,636			704,440			
Calc. check *B*	203,000			736,000			

* Average speed train resistance used.
** Not adjusted for series connection—see text.

While experience with energy and I^2t values has been rather limited, it would seem justifiable to suppose that reasonable accuracy may be expected.

In general the results have been surprisingly accurate considering the present approximations used for the various curves.

As might be expected the saving in time is considerable. The graphical solution on check *A* required some 6 or 7 hours. The electrograph calculations would probably require 10 or 15 minutes if the meters read directly in feet, kilowatt-hours, etc., but an extra period of 10 minutes was necessary to convert readings into the usual speed-time curve units.

In the experimental work, some difficulty was experienced with commutator ripple. However, this was easily eliminated by the use of proper chokes and condensers. While the rotating brush seemed to make very good contact on the rest of the segments, bad contact on the small starting segment caused low *I*-current readings. This should be eliminated by better commutator and brush design. Since the characteristic of a vacuum tube depends upon the grid voltage so long as the tube is not overloaded, no trouble was experienced in holding the curves as originally adjusted. As might have been expected iron core inductances proved unsuitable, due to eddy currents, hysteresis losses, and the changing value of the inductance during the cycle.

While the accuracy of the machine is, of course, limited to the accuracy of the meters, it might be pointed out that this inaccuracy was reduced to a minimum by using the same meters for both setting the curves and for final values.

From the results already obtained it is hoped that a machine may be built at the University which will include provisions for changing motors and gear ratios easily.

It may be pointed out that while the machine has been designed expressly for speed-time curve calculations it might be used for a variety of electrical calculations on test circuits.

Appendix

The usual method of calculating and plotting speed-time curves is illustrated by the curves of figure 9, the 3 "general formulas" which follow, and the calculations of table III, all of which are for "check A" discussed in the body of the paper.

General Formulas

$$\frac{T-R-G}{100W} = \frac{T-R-G}{618.8} = A, \text{ in miles per hour per second} \quad (9)$$

$$\Delta t = \Delta V/A, \text{ in seconds} \quad (10)$$

$$\Delta s = \left(\frac{2V+\Delta V}{2}\right)(\Delta t)(1.467), \text{ in feet} \quad (11)$$

Under "general formulas," above, 3 equations are listed which apply to every step shown in the solution. Equation 9 is the same as equation 1 in the body of the paper except that the term for the curve resistance C has been omitted, since, in this check run, the calculations are for straight track only. In equation 1 the term $100 W\frac{dV}{dt}$ represents the force necessary to overcome the inertia for both

Table III—Calculations of Check "A"

Between Points	Speed V+ΔV	T (Avg)	R (Avg)	G	A (Avg)	Speed ΔV	Time Δt	Time t+Δt	Distance ΔS	Distance S+ΔS	I**	I²
a, b	26.0	1000	88*	0	1.474	26.0	17.63	17.63	336	336	108	11,664
b, c	30.0	850	94	0	1.220	4.0	3.28	20.91	135	471	83	6,889
c, d	35.0	575	111	0	0.750	5.0	6.67	27.58	318	789	62	3,884
d, e	40.0	375	132	0	0.393	5.0	12.72	40.30	700	1,487	49	2,401
e, f	45.0	238	156	0	0.132	5.0	37.76	78.06	2,350	3,837	40	1,600
f, g'	46.0	188	172	0	0.026	1.0	38.68	116.74	2,580	6,417		
f, g	45.5							88.00		4,500	39	1,521
g, h	42.0	213	163	170	−0.194	− 3.5	18.05	106.05	1,159	5,659	45	2,025
h, i	40.0	275	149	170	−0.071	− 2.0	28.13	134.18	1,690	7,349	49	2,401
i, j	39.5	300	143	170	−0.021	− 0.5	23.80	157.98	1,388	8,737	50	2,500
j, k	39.5	312	142	170	0.000	0.0	26.40	184.38	1,530	10,267	50	2,500
k, l	42.0	275	148	0	0.205	2.5	12.20	196.58	729	10,996	45	2,025
l, m	44.0	225	159	0	0.107	2.0	18.76	215.34	1,183	12,179	41	1,681
m,n'	46.0	200	170	0	0.048	2.0	41.30	256.64	2,730	14,909		
m, n	45.5							238.00		13,729	39	1,521
n, o	41.0	0	160	0	−0.259	− 4.5	17.40	255.40	1,103	14,832		
o, p	36.0	0	136	0	−0.220	− 5.0	22.74	278.14	1,284	16,116		
p, q	30.0	0	113	0	−0.183	− 6.0	32.90	311.04	1,590	17,706		
q, r'	24.0	0	90	0	−0.145	− 6.0	41.30	352.34	1,637	19,343		
q, r	26.7							331.00		18,481		
r, s'	32.0	0	99	−190	0.147	5.3	36.01	367.01	1,552	20,033		
r, s	31.0	0						360.00		19,713		
s, t	0.0	−1040†	58	−190	−1.468	31.0	21.10	381.10	480	20,193		

* At end of Starting Period. ** For $V + \Delta V$. † Braking Force Per Motor.

Starting kilowatt-hours at 600 volts = (17.63) (600) (108) ÷ (1,000) (3,600) = 0.317

Starting I^2t = (17.63) $(108)^2$ = 205,636

Total kilowatt-hours at 600 volts = 2.044 (from area under current curve)

Total I^2t = 704,440 (from area under current-squared curve)

Total kilowatt-hours for 4 motors = (2.044 − 0.317/4)4 = 7.859

translation and the rotation of wheels and axles, motor armatures, etc. The grade resistance G is 20 pounds per ton per motor for every one per cent of grade while curve resistance is usually taken as 0.6 of a pound per ton per motor for every degree of curvature. The train resistance per motor is plotted before hand, as in figure 4, from any one of several empircal formulas which have been developed for this purpose, or from actual test curves for a particular car or train.

Equation 10 simply states the relation that the time necessary for a certain change in velocity in miles per hour is equal to the change in velocity divided by the acceleration in miles per hour per second.

In equation 11 the change in distance (from the starting point) is given by the average speed multiplied by the change in time and by a constant to give the distance in feet.

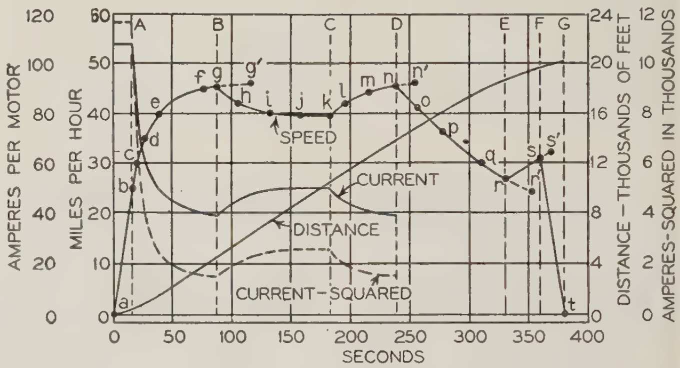
Construction of Curves

To illustrate the construction of the curves of check A the first few steps may be explained. For a starting current of 108 amperes the tractive effort per motor will be constant at 1,000 pounds until the car speed has reached a value of 26 miles per hour, from figure 3. The train resistance for this period is usually assumed to be the resistance at the end of the period (to allow for initial starting resistance) which is 88 pounds per motor, from figure 4. For level straight track G is zero. ΔV then, is first taken as 26 miles per hour and equation 9 gives the acceleration to be 1.474 miles per hour per second. Equation 10 gives the time for this change in velocity to be 17.63 seconds and equation 11 shows that the car has progressed 336 feet. This may be plotted as shown by the straight line drawn between points a and b on the speed-time curve of figure 9.

For the next step a change in velocity is assumed. For great accuracy ΔV should be as small as practical consideration will permit. If ΔV = 4 miles per hour then the average tractive effort during this period, from figure 3, is 850 pounds and the average train resistance per motor is 94 pounds, from figure 4. Δt and Δs are calculated as before and the total time is, of course, $t + \Delta t$ where the total time t up to the point b is 17.63 seconds. Line bc on the curve may now be plotted.

As these calculations are performed, step by step, the speed-time and distance-time curves are drawn. This process is continued until the point g' on the speed-time curve gives a distance greater than the distance from the starting point to the first change in grade. Table I (in the paper) shows this to be 4,500 feet, so a line B drawn to cross the distance curve at 4,500 feet intercepts the speed-time curve at g, so values for step fg are read from the drawing and the time indicated by line B is 88 seconds.

Fig. 9. Graphical check "A"



From the profile outlined by table I the car now goes up a 1.373 per cent grade so G becomes:

(1.373) (20) (6.188) = 170 pounds

and the calculations are performed as before.

Continuing in this process the distance curve finally shows the stopping point for the run has almost been reached. A braking force, in this case 1,040 pounds to correspond to the electrograph conditions, is used with a minus sign as T in equation 9 and the car is brought to a stop at the point t.

The current per motor may be obtained for each speed from figure 3 and I^2 may be calculated. Both curves are then plotted as shown in the figure. From these curves the kilowatt-hours at 600 volts and the (amperes)² (seconds) may be calculated as shown below the listed calculations of table III. The kilowatt-hours at 600 volts have been calculated to check the electrograph results. These figures must be adjusted as explained in the paper to obtain actual kilowatt-hours for the car.

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Loads on Delta-Connected Transformers With Mid-Taps

Mid-taps on the secondaries of a 3-phase delta-connected transformer bank enable loads to be supplied simultaneously at full voltage and half voltage. Although the nonuniform loading of the different windings makes an exact determination of the maximum permissible loads difficult, equations and curves have been developed to facilitate these calculations. A rating factor is included which permits the rating of the transformer bank to be expressed in terms of the maximum current in any portion of the windings. Equations for voltage regulation with balanced loads and similar transformer units have been developed.

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It is sometimes advantageous to supply simultaneously 2 3-phase loads, one at half voltage and the other at full voltage, from a transformer bank with delta connected secondary having mid-taps. When this connection is to be used, it is necessary to determine the amount of 3 phase loads which can be carried safely at one voltage, provided the amount of load to be carried at the other voltage is known. Consideration should also be given to the voltage regulation, since it is evident that the regulation for a given 3 phase bank loaded to capacity in this manner will not be as good as if it were loaded to capacity normally.

It is difficult to determine exactly the maximum load permissible with this connection, because of the nonuniform loading of the various windings of the transformers. However, the equations and curves presented in this paper include a rating factor which permits the rating of the transformer bank to be expressed in terms of the maximum current in any portion of the transformer windings. Two sets of curves are given for determining simultaneous loading. The curves of one set (figure 3) are based upon the maximum current in any portion of the winding being limited to rated current. The curves of the other set (figure 5) are based upon a maximum current of 110 per cent rated current, and upon the additional restriction that the copper loss will not exceed that at rated load.

Previous papers have analyzed the problem for the special case where the power factors of the 2 loads are equal. In this paper the solution has been generalized to include the effect of different power factors for the 2 loads.

Voltage regulation is considered briefly, and general equations are given for the voltage regulation for this type of connection, for the case where the load on the 3 phases is balanced and the bank is made up of similar units. A table shows the results of calculations made for 3 typical transformer banks.

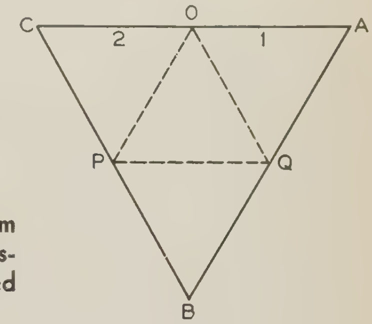

Fig. 1. Schematic diagram of delta-connected transformer with load connected to half voltage taps

Figure 1 shows the schematic diagram for the type of connection under consideration. In this diagram the dotted lines represent the half voltage delta formed by the mid-taps of the secondary windings.

Determination of Allowable Loadings

If 2 balanced 3 phase loads of any power factors are connected to a transformer bank in this manner, the load currents of the full and half voltage loads are not in phase with each other. The kilovolt-ampere capacity of the bank that can be utilized will depend upon the permissible percentage of rated current which can be carried in any portion of the windings, the relative amounts of full and half voltage load, and the power factors of the 2 loads.

The vector diagram of the currents flowing in the secondary windings of the transformer bank is shown in figure 2. Since the circuit is symmetrical and the loads are assumed to be balanced 3 phase loads,

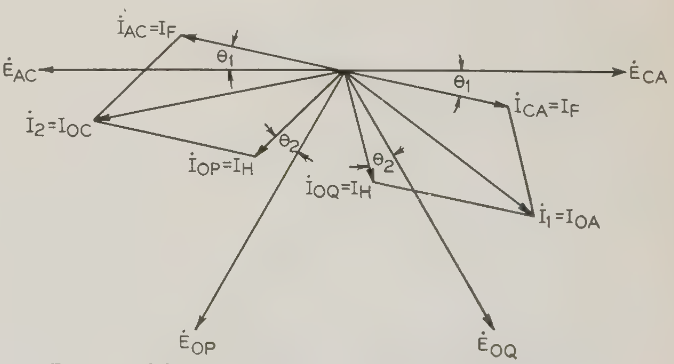

Fig. 2. Vector diagram of currents in winding CA

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the vector diagram, for simplicity, is shown only for the one phase, AC. In the diagram:

I_F = scalar value of winding current due to full voltage load.
I_H = scalar value of winding current due to half voltage load.
ϕ_1 = power factor angle of full voltage load.
ϕ_2 = power factor angle of half voltage load.

With the voltage CA used as a reference, the following equations, written in complex form, give the currents in the various portions of the winding CA:

$$\begin{aligned} I_{OA} &= I_F(\cos\phi_1 - j\sin\phi_1) + I_H(0.5 - j0.866)(\cos\phi_2 - j\sin\phi_2) \\ &= I_F\cos\phi_1 + 0.5\, I_H\cos\phi_2 - 0.866\, I_H\sin\phi_2 - \\ &\quad j(I_F\sin\phi_1 + 0.5\, I_H\sin\phi_2 + 0.866\, I_H\cos\phi_2) \end{aligned} \tag{1}$$

$$\begin{aligned} I_{OC} &= -I_F(\cos\phi_1 - j\sin\phi_1) + I_H(-0.5 - j\,0.866)(\cos\phi_2 - j \\ &\quad \sin\phi_2) = -I_F\cos\phi_1 - 0.5\, I_H\cos\phi_2 - 0.866\, I_H\sin\phi_2 + \\ &\quad j(I_F\sin\phi_1 + 0.5\, I_H\sin\phi_2 - 0.866\, I_H\cos\phi_2) \end{aligned} \tag{2}$$

I_P = current in primary winding

$$= \frac{1}{a}\left[\frac{I_{OC} - I_{OA}}{2}\right] \text{where } a = \text{ratio of transformation}$$

$$= \frac{-2I_F\cos\phi_1 - I_H\cos\phi_2 + j(2I_F\sin\phi_1 - I_H\sin\phi_2)}{2a} \tag{3}$$

From the vector diagram of figure 2 it can be seen that:

$$I_{OA} = I_{OC} \text{ when } \phi_1 = \phi_2 \tag{4}$$

$$I_{OA} > I_{OC} \text{ when } \phi_1 > \phi_2 \tag{5}$$

$$I_{OA} < I_{OC} \text{ when } \phi_1 < \phi_2 \tag{6}$$

Equations 4, 5, and 6 show that for all cases, except for the particular case when the power factors of the 2 loads are equal, the current in one half of each secondary winding is larger in magnitude than the current in the other half. Since the current in the primary winding, as shown by equation 3, is $^1/_2$ the vector difference of the 2 secondary currents, it follows that the portion of the secondary winding carrying the greatest current will be the limiting factor in determining the safe loading for the transformer. If the current in this portion of the winding is limited to its rated value, the other half of the secondary winding and the entire primary winding will carry less than rated current. Since, then, practically $^3/_4$ of the copper in the transformer will carry less than rated current, the maximum hot-spot temperature in the windings will be lower than if all portions of the windings carried rated current. Hence, the loading of the bank can be increased somewhat above that based upon rated current in the half of the secondary winding carrying the greatest current. The amount of increase will be that which will raise the maximum hot-spot temperature of the windings to the same point as would be found if the transformer were carrying normal rated load. The determination of this allowable increase for any particular loading of a given transformer bank is, of course, difficult, if not practically impossible. In case it cannot be determined, a conservative rating should be used, such as one based upon rated winding current, or one with but little allowance made for decreased loading of other portions of the windings.

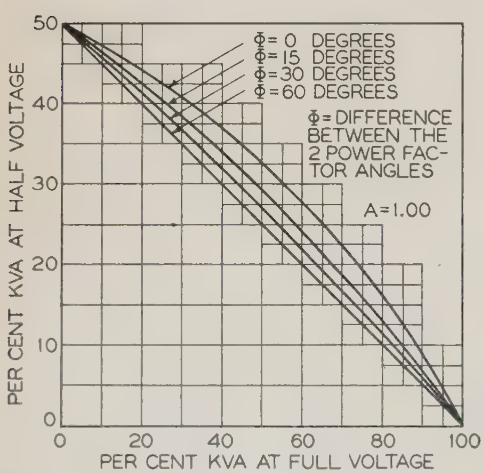

Fig. 3. Curves for determining permissible simultaneous full and half voltage loads, based upon rating factor of 1.00

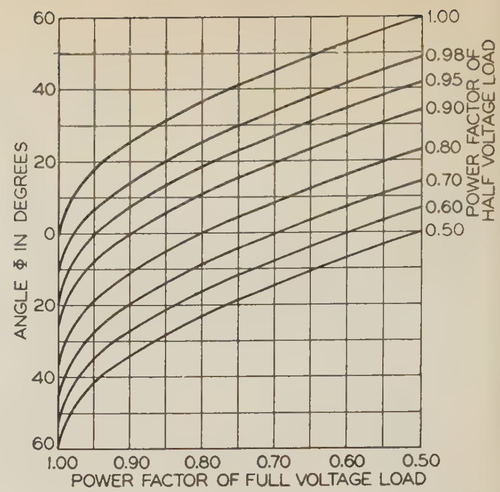

Fig. 4. Curves for determining difference between power factors of full and half voltage loads

A Factor for This Increase in Loading

The equations which follow for determining the permissible loadings of the transformer bank for various conditions contain a factor A by means of which the permissible loading may be based upon a value of current greater than rated current. If I_R is the rated current of each half of the secondary winding, and if AI_R is the permissible current which may be carried in either half of the winding, where A is the increased rating factor previously mentioned, equations 1 and 2, respectively, may be expanded and equated to AI_R.

$$I_{OA} = A\, I_R$$

or

$$I_F^2 + I_H^2 + I_F I_H[\cos(\phi_2 - \phi_1) - \sqrt{3}\sin(\phi_2 - \phi_1)] - A^2 I_R^2 = 0 \tag{7}$$

$$I_{OC} = A\, I_R$$

or

$$I_F^2 + I_H^2 + I_F I_H[\cos(\phi_2 - \phi_1) + \sqrt{3}\sin(\phi_2 - \phi_1)] - A^2 I_R^2 = 0 \tag{8}$$

These scalar equations are the basic equations for use in determining permissible full and half voltage loadings on the transformer bank. If the full voltage load is known in terms of the rating of the bank, that is

$$I_F = PI_R$$

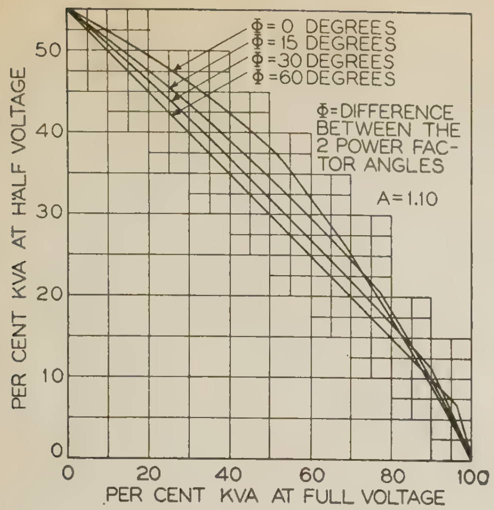

Fig. 5. Curves for determining permissible simultaneous full and half voltage loads, based upon rating factor of 1.10

where P is the ratio of full voltage load to the rated kilovolt-amperes of the bank, and PI_R is substituted for I_F in equations 7 and 8, then these equations can be solved for I_H. If Φ = the difference between the 2 power factor angles, that is

$$\Phi = (\phi_2 - \phi_1) = (\phi_1 - \phi_2)$$

then I_H may be expressed as follows

$$I_H = \frac{I_R}{2}\left\{ \begin{array}{l} -P(\cos\Phi + \sqrt{3}\sin\Phi) + \\ \sqrt{P^2(\cos\Phi + \sqrt{3}\sin\Phi)^2 - 4\,(p^2 - A^2)} \end{array} \right\} \qquad (9)$$

or if I_H is known in terms of I_R

$$I_F = \frac{I_R}{2}\left\{ \begin{array}{l} -2P_1(\cos\Phi + \sqrt{3}\sin\Phi) + \\ \sqrt{4P_1^{\,2}(\cos\Phi + \sqrt{3}\sin\Phi)^2 - 16P_1^{\,2} + 4A^2} \end{array} \right\} \qquad (10)$$

where

$$2P_1 = \frac{I_H}{I_R}$$

From these equations it can be seen that the permissible loading which can be placed on either the full or half voltage delta, providing the load on one is known, depends upon the difference in power factor angles and the value of the factor A. The curves of figure 3 have been computed using equation 9 but have been converted to a kilovolt-ampere base. They show the permissible simultaneous loads which can be carried on the transformer bank. The curves of figure 3 are based upon a value of unity for the rating factor A. That is, the values of permissible loading taken from these curves will be such that in no part of the windings will the current exceed rated value. The curves of figure 4 can be used to determine quickly the difference in power factor angles for any 2 power factors.

The curves of figure 5 are similar to those of figure 3. They are based upon a value of 1.10 for the rating factor A, and upon the additional restriction that the copper losses in the bank will in no case exceed the rated full load copper loss. The necessity for this restriction can be seen by considering the case where the known load on the full voltage delta is near the bank rating. For example, if the load on the full voltage delta is 90 per cent of the bank rating, the permissible half voltage loading based upon equation 9 will be such that the copper loss will be considerable in excess of the rated full load copper loss. The curves of figure 5 are shown only in order to give the relative increase in rating as the factor A is increased. The value of 1.10 used here for the rating factor is of course an arbitrary figure and it cannot be said that this figure will be a safe value for any transformer bank. In any case of doubt, the curves of figure 3 should be used.

Voltage Regulation

The determination of the voltage regulation of the full and half voltage loads for this type of connection involves the use of the 3-winding equivalent circuit of the single-phase transformers making up the bank. Consider the single-phase transformer AC of the bank shown in figure 1, the equivalent circuit for which is shown in figure 6. This equivalent circuit is determined from simple short-circuit impedance tests on the transformer. The currents in the primary winding and in each half of the secondary winding of the transformer can be determined by means of equations 1, 2, and 3, and the regulation may be determined by making use of the following relationships.

$$V_{OC} = E_p - I_pZ_p - I_{OC}Z_{OC} \qquad (11)$$

$$V_{OA} = -E_p + I_pZ_p - I_{OA}Z_{OA} \qquad (12)$$

$$V_{AC} = \frac{V_{OC} - V_{OA}}{2}$$

$$= E_p - I_pZ_p - \frac{(I_{OC}Z_{OC} + I_{OA}Z_{OA})}{2} \qquad (13)$$

$$V_{OQ} = \frac{V_{OA} + V_{OC}\left(\epsilon^{\frac{j\pi}{3}}\right)}{2}$$

$$= \frac{-E_p + I_pA_p - I_{OA}Z_{OA} + (E_p - I_pZ_p - I_{OC}Z_{OC})\left(\epsilon^{\frac{j\pi}{3}}\right)}{2} \qquad (14)$$

where

E_p = primary impressed voltage in direction AC
V_{AC} = voltage of full voltage delta
V_{OQ} = voltage of half voltage delta
$\epsilon^{\frac{j\pi}{3}}$ = an operator rotating a vector 60 degrees forward

and

all impedances and voltages are referred to the primary

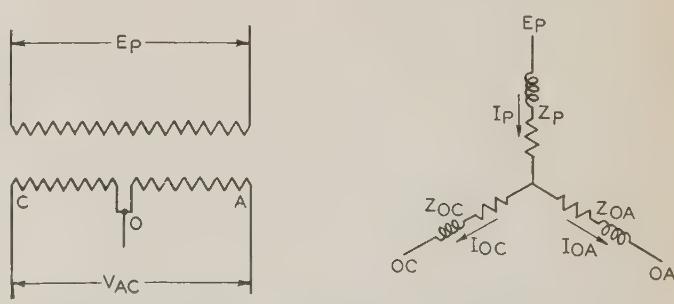

Fig. 6. Diagram of single-phase transformer AC of figure 1, and its equivalent circuit when used as a 3-winding transformer

The equivalent 3-winding circuits were determined for 3 different distribution transformers of recent manufacture. The transformers were of the low impedance type. Table I shows the calculated full-load voltage regulation of 3 3-phase banks made up of the types of transformers for which the equivalent 3-winding circuits were determined. The results show that the regulation of the banks when carrying load from the mid-taps, in all cases is poorer than when carrying full voltage load. The regulation of the half voltage load is considerably greater than for the full voltage load, for all 3 banks. It also should be noted that, although the regulation of bank 3 loaded to capacity normally is greater than for either bank 1 or bank 2, yet bank 3 is much more suitable for carrying simultaneous loads. This well illustrates the fact that the rated per cent impedance of the transformers is not a satisfactory measure of their suitability for use in delta secondary banks to carry simultaneous full and half voltage loads. It shows that in order to avoid poor regulation for this type of connection it is necessary to use transformers having the 2 halves of the secondary windings properly interlaced.

If this connection is to be used for an installation where the voltage regulation cannot be excessive, it is apparent that it is necessary to determine the 3-winding constants of the transformers and then calculate the regulation.

Table I—Calculated Full Load Voltage Regulation of 3 Banks of Transformers, for 2 Loading Conditions

	Bank 1	Bank 2	Bank 3
Transformer			
Number	3	3	3
Size, each	50 kva	25 kva	50 kva
Voltage	2,170/240/120	2,170/240/120	2,170/240/120
Type	Core	Core	Shell
Normal Load[1]			
Regulation	1.65%	1.7%	1.95%
Simultaneous Loads[2]			
Regulation			
Full voltage delta	2.6 %	2.9%	2.05%
Half voltage delta	5.5 %	6.5%	3.1 %

1. Normal load: 100 per cent rated kilovolt-amperes at 0.8 power factor.
2. Simultaneous loads: 50 per cent rated kilovolt-amperes of full voltage load; 32.5 per cent rated kilovolt-amperes of half voltage load; both loads at 0.8 power factor.

Lightning Investigation on Transmission Lines—V

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Continuing an investigation of lightning effects on power transmission lines, a recent study confirms previously reached conclusions as to the effectiveness of overhead and buried ground wires. Also, direct stroke surge currents of from 2,000 to 100,000 amperes in tower structures were measured with the surge crest ammeter, and total stroke currents up to 220,000 amperes were indicated. Values for the rate of build-up of direct stroke currents and values of potentials in the tower were obtained. Negative polarity clouds were found to be the source of almost all direct strokes.

THE investigation of lightning effects on transmission lines which has been carried on for several years and has been reported in previous A.I.E.E. papers[1,2] was continued in 1934. The present paper is the sixth of a series reporting the results of this investigation.

The 2 lines described in the immediately preceding paper (see reference 2, part IV) were again used for the investigation; these lines are the Wallenpaupack-Siegfried 220 kv line, and the Glenlyn-Roanoke 132 kv line.

The conclusions which were reached as the result of the latest study may be summarized as follows:

1. The year 1934 confirmed the conclusion previously reached as to the effectiveness of overhead ground wires and counterpoises. On the Wallenpaupack-Siegfried line there were 14 flashed towers, all of which were on the section without overhead ground wires. On the whole Pennsylvania-New Jersey interconnection (346 miles) there were 12 tripouts, 11 of which were due to flashover on the 37 miles of Wallenpaupack-Siegfried line without ground wires and 1 of which occurred on the section of the Bushkill-Roseland line between Bushkill and the Delaware River, which has overhead ground wires. However, on this section no particular effort has been made to secure low tower footing resistance.

2. If a stroke current emerges from a line conductor, flashover of the line insulation will follow.

3. Conventionally placed overhead ground wires 10 to 20 feet above the line conductor at the towers have been found in practice effectively to shield the conductors from direct strokes.

4. If a ground wire or tower is struck and the tower footing re-

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1. For all numbered references, see list at end of paper.

sistance is high enough, insulator flashover will follow due to the high potential of the tower structure.

5. A counterpoise (buried ground wire) serves effectively to reduce ground current density at the tower base and hold down tower potential, thereby preventing insulation flashover.

6. Readings of direct stroke surge currents in tower structures were obtained with the surge crest ammeter, and showed a range from 2,000 to 100,000 amperes.

7. Probable stroke currents ranged from 2,500 to 220,000 amperes.

8. Difference of potential in the tower from top to bottom has not exceeded 100,000 volts, but the whole tower may be raised above ground by a voltage equal to the flashover of the line insulation.

9. In 2 years 97 per cent of all direct strokes to 2 transmission lines were from negative polarity clouds.

10. For an isokeraunic level of 30 to 40 storms per year, records of 42 strokes per 100 miles per year were obtained.

11. From a cathode ray oscillogram of conductor potential under direct stroke conditions, the direct stroke current building up from the line structure appeared to increase approximately in accordance with the relation:

$$i = 300\epsilon^{0.8t}$$

in which t is time in microseconds and i is current in amperes. This means that in 4 microseconds a current of 8,000 amperes would be reached and in 8 microseconds a current of 200,000 amperes would be reached. Insulator flashover takes place in 4 to 8 microseconds.

Line and Measuring Equipment

The 2 lines used for the investigation are the Wallenpaupack-Siegfried 220 kv line of the Pennsylvania Power and Light Company, and the Glenlyn-Roanoke 132 kv line of the Appalachian Electric Power Company (American Gas and Electric Company's system). These lines were described in the preceding paper of this series (see reference 2, part IV). In addition to the equipment previously described, the Pennsylvania line had all 4 legs of 150 towers (out of a total of 314 towers) equipped with surge crest ammeter[3] magnetic links, also links were installed on the counterpoise wires at about 8 towers. Figure 1 illustrates the equipment used at a typical tower on this line.

The Glenlyn-Roanoke line had 150 towers (out of a total of 267 towers) equipped with magnetic links on all 4 legs, in addition to a number of links on the counterpoise wires. A crater lamp oscillograph[4] was installed on this line at Roanoke. Figure 2 illustrates the arrangement of equipment at a typical tower.

Lightning Currents in Towers and Strokes

The surge crest ammeter is adapted to the measurement of both oscillatory and unidirectional surges.[3] During the 1933 and 1934 lightning seasons, records from this instrument have indicated lightning stroke surge currents in tower structures to vary from strictly unidirectional polarity surges to an extreme case of 44 per cent oscillation, that is, the second half cycle was 44 per cent in amplitude of the first half cycle. In general, the higher current lightning surges were of unidirectional polarity, and the lower surges tended toward some degree of oscillation. Additional measurements and study are required before a good interpretation of these results can be made. There are a number of considerations which must be weighed carefully as having possible significance in connection with the indicated oscillations. Particularly, the recently indicated complexity of the stroke mechanism must be borne in mind.[8,9,11] A lightning flash may consist of one or more main strokes, each of which is preceded by a leader stroke. The single stroke and the first stroke of a number of successive strokes are preceded by a leader stroke of different character than the leader stroke preceding subsequent main strokes. Within this complicated mechanism may lie the explanation of the indicated oscillations.

Table I summarizes the readings taken on the Wallenpaupack-Siegfried line during the years 1933 and 1934, both for individual tower currents and for probable stroke currents. The latter figure is made up by adding the currents in all the towers affected by a stroke. Where more than one tower is involved, data are given under the heading "tower current" for only the tower with the highest current. The maximum current in one tower recorded on this system in the 2 years was 51,000 amperes and the maximum stroke current was 107,000 amperes. As many as 7 towers have been affected by 1 stroke.

In table II are summarized similar data for the Glenlyn-Roanoke line for the years 1933 and 1934. The maximum current in one tower recorded for this system during 1933 and 1934 was 100,000 amperes. The maximum stroke current was 220,000 amperes.

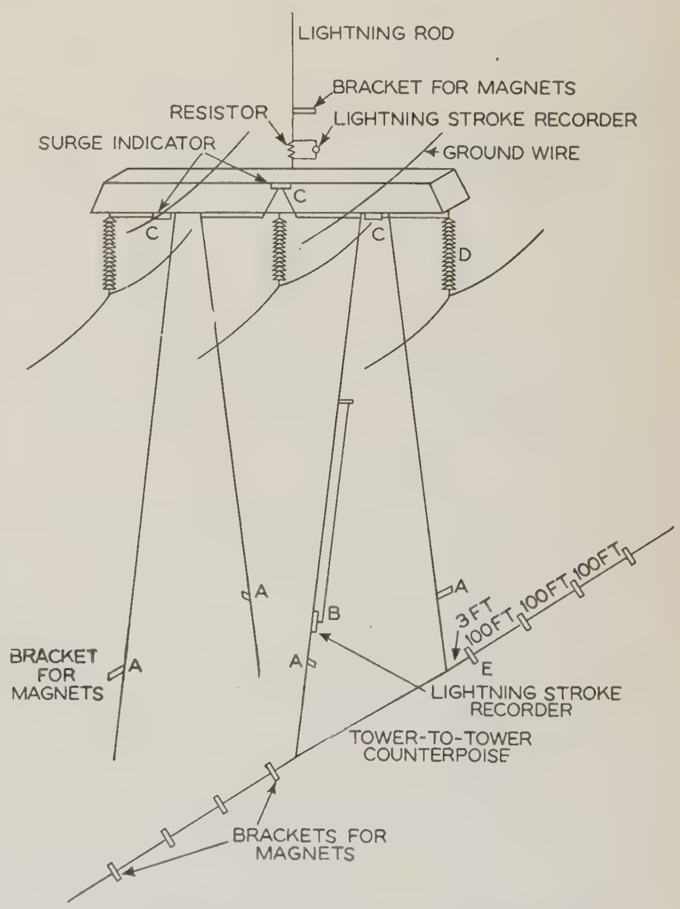


Fig. 1. Diagram of tower of Wallenpaupack-Siegfried 220 kv line, illustrating location of measuring and recording equipment

On 2 occasions as many as 8 towers were involved in 1 stroke.

All currents recorded on the Wallenpaupack system were of negative polarity. On the Glenlyn system there was 1 positive polarity tower current of 7,600 amperes in 1933, and in 1934 2 positive polarity tower currents: 1 of 36,000 amperes and 1 of 100,000 amperes. The probable stroke current in these 3 cases was 7,600, 36,000 and 193,000 amperes, respectively, of positive polarity. All other current readings on this line were of negative polarity.

In figure 3 are drawn some cumulative curves for tower currents and stroke currents, based on the data of tables I and II. It will be seen from these curves that only about 10 per cent of the tower currents are greater than 60,000 amperes, and about 10 per cent of the stroke currents greater than 100,000 amperes.

Potential Difference Across Vertical Section of Tower

The lightning stroke recorders shunted across 40 feet of the height of the tower leg on the Wallenpaupack-Siegfried line recorded voltages from 3 kv to more than 50 kv. In the latter case, the film of the instrument flashed over. About 90 per cent of the voltages were under 40 kv. The range and distribution of these potential differences for 1933 and 1934 are given in table III. Figure 4 shows a cumulative curve based on the data of table III.

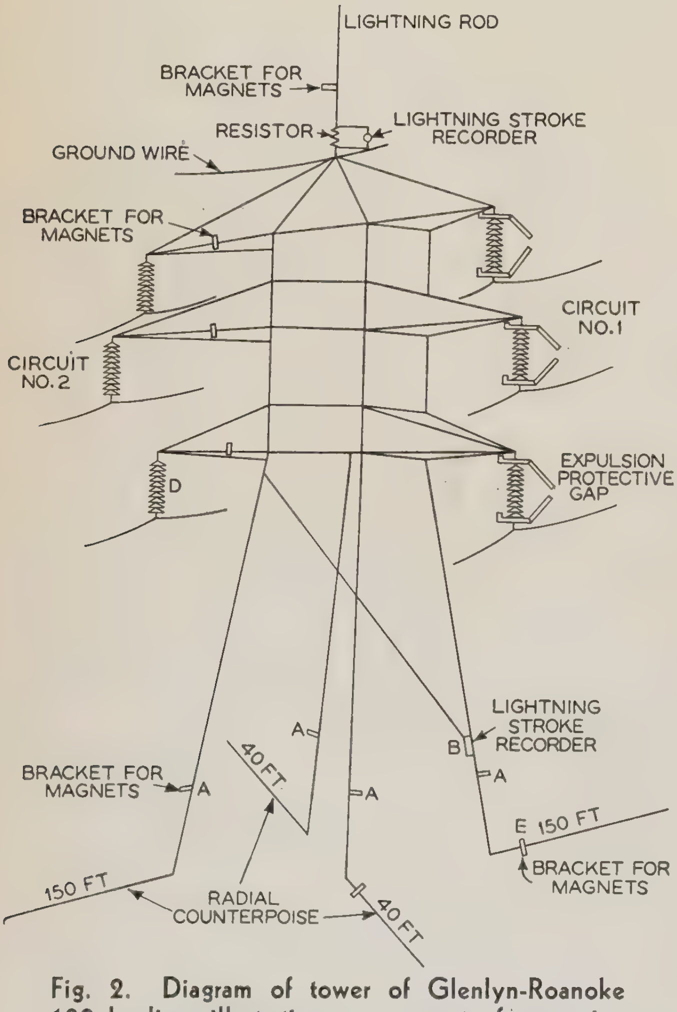


Fig. 2. Diagram of tower of Glenlyn-Roanoke 132 kv line, illustrating arrangement of measuring and recording equipment. Lightning stroke recorders not in use on this line in 1934

Table I—Tower and Stroke Currents
Wallenpaupack-Siegfried 220 Kv Line

Range of Current Amp.	Number of Occurrences: Tower Currents* 1933	Tower Currents* 1934	Probable Stroke Current 1933	Probable Stroke Current 1934
1,000– 5,000	4	4	4	4
5,001– 10,000	3	5	3	1
10,001– 20,000	7	2	6	4
20,001– 30,000	0	0	1	2
30,001– 40,000	6	2	3	0
40,001– 50,000	2		4	1
50,001– 60,000	1		1	0
60,001– 70,000			0	0
70,001– 80,000			1	0
80,001– 90,000				0
90,001–100,000				0
100,001–110,000				1
Total	23	13	23	13

* Where more than one tower is involved, data are given in this table for only the tower with highest current.

All current records are of negative polarity, that is, top of tower negative with respect to ground.

As shown in table III, field data pertaining to voltages across the tower structure during the flow of lightning currents show that these potentials are a very small portion of the total voltage required for insulator flashover. A maximum of 100 kv from tower top to ground is indicated and the great majority are below 50 kv., and many too low to be measurable (below 5 kv). Measurements of potentials on line conductors show direct strokes giving potentials limited only by insulator flashover. The rate of rise of potential is not rapid, however, requiring in one case 5 microseconds to flash over.

Polarity Relation in Direct Strokes

In almost all cases of direct strokes to transmission lines the lightning current apparently flows up the tower, i. e., in conventional terminology the tower base is positive and the tower top negative in polarity. Of 109 stroke records accumulated with the surge crest ammeter, which is an ideal indicator of direction of current flow, 106 records show upward flowing current. Assuming that upward flowing direct stroke currents in tower legs are discharge currents between a negative polarity cloud area and a positive polarity induced charge at the ground, the percentage of negative cloud strokes is 97 and positive cloud strokes 3. An observer[5] recently reporting stroke cloud polarities obtained from general field studies and not associated with transmission lines gives approximately 80 per cent for negative clouds and 20 per cent for positive clouds. These figures are for strokes between earth and cloud. Accumulated totals of 7,128 field changes, including both cloud-to-cloud and cloud-to-ground strokes,

gave 63 per cent from negative clouds and 37 per cent positive.

As 37 per cent of the total field changes were from positive polarity clouds and only 20 per cent of the field changes associated with cloud-ground strokes

Table II—Tower and Stroke Currents

Glenlyn-Roanoke 132 Kv Line

Range of Current Amp.	Number of Occurrences: Tower Currents* 1933	1934	Probable Stroke Current 1933	1934
1,000– 5,000	0	2	0	2
5,001– 10,000	8	3	7	3
10,001– 20,000	9	7	10	2
20,001– 30,000	4	11	2	10
30,001– 40,000	0	15	1	11
40,001– 50,000	0	5	1	7
50,001– 60,000	1	2	0	1
60,001– 70,000	1	3	1	0
70,001– 80,000		0	0	3
80,001– 90,000		0	0	2
90,001–100,000		2	0	1
100,001–110,000			0	1
110,001–120,000			1	1
120,001–130,000				1
130,001–140,000				2
190,001–200,000				1
200,001–210,000				0
210,001–220,000				2
Total	23	50	23	50

* Where more than one tower is involved data are given in this table for only the tower with highest current.

All current records are of negative polarity, except 1 in 1933 and 2 in 1934.

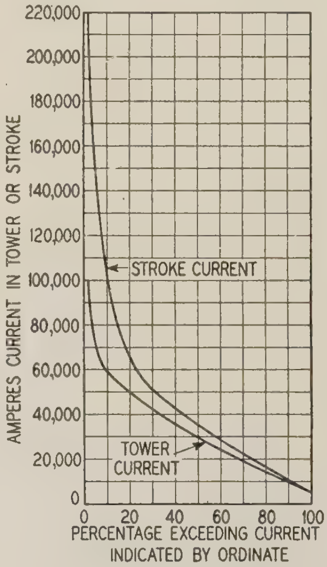
were from positive clouds, it is strongly indicated that many positive cloud strokes are the cloud-to-cloud or cloud-to-space type. This is in accordance with observations pertaining to the extensive ramification of streamers from positive clouds.[5,6]

Now the 20 per cent positive polarity cloud-ground strokes compared with only 3 per cent positive polarity strokes which get on the transmission line, show the line to be much more susceptible to negative polarity strokes. The authors have pointed out[7] how this circumstance fits in with the directive effects of a conducting projection above the plane of the seat of the positive charge. The transmission line acting as such projection above the positive charge on the earth serves as an origin from which the stroke builds up to the cloud. Laboratory tests using small scale models indicate that under these conditions all negative cloud strokes within a distance of 10 to 20 times the height of the line will emanate from the line and build upward to the seat of the negative electrification in the cloud. The excellent photographs,[8,9] recently obtained with the Boys camera have recorded this building up of the main stroke. A preliminary stepped streamer of very long time formation apparently provides initial ionization for the starting of the initial main stroke. The location of this preliminary ionization may, of course, determine the point of contact of the stroke at the tower top, on the ground wire, or on the conductor. Cases of direct strokes to conductors which are apparently well shielded by overhead ground wires may be caused by line excitation controlling the direction of the preliminary ionizing streamer. The Boys camera photographs have confirmed early observations[10] that many strokes are made up of repeated discharges through the same breakdown channel, and another investigation[11] has shown such strokes frequently to strike the transmission line.

The 109 records of lightning stroke currents referred to above were obtained on 130 miles of line over a 2 year period of time. This gives an expectancy of 42 strokes per 100 miles per year for the territory traversed by the lines, which is in an isokeraunic region of 30 to 40 storms per year.

Analysis of Various Cases of Direct Strokes to Transmission Lines

The complete electrical mechanism of the lightning stroke, insulator flashover, and line tripout is, of course, complicated. Accumulated data have, however, shown that the really significant elements are not many and fit together in a very simple way.



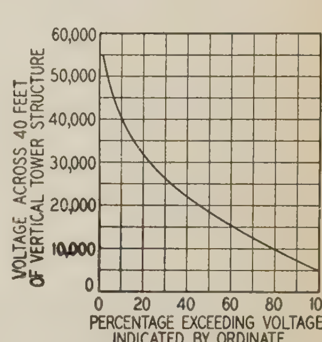


Fig. 4 (above). Cumulative curve of voltage across 40 feet vertical of tower on Wallenpaupack - Siegfried line during 1933 and 1934

Fig. 3 (left). Cumulative curve of tower and stroke currents recorded during 1933 and 1934, on Wallenpaupack-Siegfried and Glenlyn-Roanoke lines

Table III—Potential Difference Across 40 Feet of Tower, From Lightning Stroke Recorder Readings

Wallenpaupack-Siegfried 220 Kv Line

Range of Volts	Number of Occurrences: 1933	1934	Total
1,000– 5,000	4	2	6
5,001–10,000	10	7	17
10,001–15,000	15	9	24
15,001–20,000	2	5	7
20,001–25,000	6	1	7
25,001–30,000	3	2	5
30,001–35,000	4	1	5
35,001–40,000	1	5	6
40,001–45,000	2		2
45,001–50,000	0		
50,001–55,000	1		
Total	48	32	8

Majority of voltage records negative, that is, top of tower negative with respect to bottom.

Case I.—Stroke to a Tower, No Ground Wires Present. When a lightning stroke builds up from a tower top with no ground wire present, the entire current feeding into the extending streamer tip, proceeding at approximately 150 feet per microsecond,[8] flows from the ground into the tower base and up through the tower structure.

Table IV—Field Record Illustrating Direct Stroke to a Tower. No Ground Wires Present

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current (A) Amp.	Tower Potential Kv	Across-Tower Potential (B) Kv	Insulator Assembly-Phase: Surge Indicator Operation (C)	Insulator Assembly-Phase: Flash Marks (D)	Line Trip-Outs	Short Circuited Phase (F)
*WT*27–6	58	−36,000	2,100	50	*Y*	*Y*	Yes	*Y*
*WT*28–1	45	− 3,000	135	64	*Y*	*Y*		

A, B, C, D indicate data recorded by instruments located as shown on figure 1. *F* indicates data recorded by magnetic oscillograph.

The lightning stroke current, obtained from a cathode ray oscillogram of conductor potential increase under direct stroke conditions, was

$$i = 300\epsilon^{0.8t}$$

in which t is in microseconds and i in amperes. This relation gives a current of approximately 700 amperes and a rate of rise of 600 amperes per microsecond at 1 microsecond, also a current of 16,000 amperes and a rate of rise of current of 13,000 amperes per microsecond at 5 microseconds. At this rate the extreme upper limit of lightning stroke current of approximately 200,000 amperes would require 8 microseconds to reach crest value. An insulator flashover at 1,800 kv due to a stroke to a tower of 50 ohms footing resistance would be reached in about 6 microseconds. This is slow compared with the time length (0.1 microsecond) of the tower structure.

At the tower base the ground current density is highest, and a potential difference appears depending upon this density and the ground resistance. The tower structure therefore is elevated in potential above ground potential by this amount while the conductors remain at practically ground potential. A voltage instantaneously equal to stroke current times tower footing resistance builds up across each insulator assembly. This potential combined with the normal excitation voltage of each conductor gives the total insulator assembly stress. As these potentials are combined with respect to polarity, a negative tower potential added to a positive conductor potential will give maximum insulator assembly stress and the phase in this condition will flash over first. One assembly flashover reduces the tower potential just as much as connecting $^1/_2$ the conductor surge impedance across the tower footing resistance would. This reduction in tower potential may be sufficient to prevent other insulator assemblies flashing over, and if so, only a single-phase flashover is obtained. If the stroke current, however, is sufficiently high again to increase the tower potential in spite of the lowered impedance to ground, additional assemblies will flash over. As tower potentials are usually negative for direct strokes to the tower, flashover will occur on the conductor having positive polarity excitation at the time of the stroke. Insulator flashover may occur at adjacent towers if the potential carried along the flashed conductors is sufficiently high. A specimen field record of such an occurrence obtained on the Wallenpaupack-Siegfried line[12] during the season 1933 is given in table IV.

These data indicate a stroke to tower *WT*27-6. At this tower 36,000 amperes flowed in the tower structure, the tower base being positive and the tower top negative in polarity. On this basis the assumption is made that a stroke occurred between the tower top and a negative polarity cloud. The measured tower footing resistance of 58 ohms gives a tower potential of 2,100 kv. The laboratory flashover of the 16 unit string ranges from 1,650 on the $1^1/_2 \times 40$ microsecond wave to 1,900 kv on the 1×5 microsecond wave. These values are exceeded by the 2,100 kv tower potential. The across-tower potential of 50 kv (from top to bottom of tower) is obviously a negligible proportion of the insulator flashover voltage. The surge indicator on *Y*-phase tower arm at 27-6 and flashover marks showed flashover to have occurred on this insulator assembly. Also, the surge indicator and flashover marks on *Y* phase of adjacent tower 28-1 showed insulator assembly flashover. The current in this tower structure was just high enough to leave a record on the surge crest ammeter, 3,000 amperes. Accompanying this lower tower current, however, was an across-tower potential of 64 kv, more voltage than at the tower where the lightning disturbance occurred. Keeping in mind the abrupt flashover of the insulators at approximately 1,800 kv, the nature of this across-tower voltage is readily apparent. Similar voltages are obtained across conduc-

Table V—Field Record Illustrating Direct Stroke to a Conductor. No Ground Wires Present

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current (A) Amp.	Tower Potential Kv	Across-Tower Potential (B) Kv	Insulator Assembly-Phase: Surge Indicator Operation (C)	Insulator Assembly-Phase: Flash Marks (D)	Line Trip-Outs	Short Circuited Phase (F)
*SR*8–1	34	−12,000	408	74	*W*	*W*	Yes	*W*
*SR*8–2	23	− 8,000	194	58	*W*	*W*		

A, B, C, D indicate data recorded by instruments located as shown on figure 1. *F* indicates data recorded by magnetic oscillograph.

tors leading to the insulator string in laboratory flashover tests. This is a traveling wave phenomenon and the wave steepness at tower 28-1 was sufficient to give 32 kv across the 40 feet of tower structure adjacent to the insulator assembly flashed over and spanned by the lightning stroke recorder connections. As the tower height is about 80 feet, the total across-tower potential is estimated at 64 kv. A line trip-out occurred with this disturbance and magnetic oscillographs indicated the flashover to be on *Y* phase. On tower 27-5, adjacent to 27-6 on the side opposite to 28-1, which was also equipped with measuring instruments, no records were obtained.

Such a disturbance record strongly indicates a stroke to a tower followed by a single-phase flashover caused by high tower potential, followed by flashover on the same phase at an adjacent tower caused by high conductor potential. Such an interpretation is also generally confirmed by many other records.

Case II.—Stroke to a Conductor, No Ground Wires Present. If, as frequently occurs, the lightning stroke to a line having no overhead ground wire emerges directly from the conductor, flashover invariably occurs. In this case the current feeds along the conductor into the stroke. Conductor potential will rise just as though the stroke were passing to ground through a resistance equal to $^1/_2$ the surge impedance of the conductor (approximately 200 ohms). This is, of course, a high resistance and will require only a moderate lightning current to give flashover even on the highest voltage lines. Insulator assemblies on adjacent towers on the phase struck are quite certain to flash over. The stroke currents now feed up through the tower structures. Again, additional assemblies may flash over, but are not quite so likely to do so, as the stroke current has been divided between 2 towers.

In the case of a stroke directly to a conductor, the conductor potential due to the stroke is invariably high enough so that line excitation is not a factor in flashover. However, the excitation will determine whether or not trip-out follows and may also be a factor in determining which conductor is struck, as previously mentioned.

An example of a field record obtained in the case of a direct stroke to a conductor on the Wallenpaupack-Siegfried line during 1933 is given in table V.

In this case all records obtained show the disturbance to be about the same at both the adjacent towers involved, *SR*8-1 and *SR*8-2. Surge indicators and flashover marks showed flashovers to have occurred on *W* phase at both towers. The line tripped out and short-circuit current indicated flashover on *W* phase. Tower currents and footing resistances gave tower potentials well below insulator flashover. Across-tower potentials were of low magnitude as compared to insulator assembly flashover voltages, but are still quite reasonable as voltage differences resulting from insulator flashover waves traveling to ground through the tower structure. This stroke quite certainly built up from *W* phase conductor in mid-span, probably nearer to *SR*8-1 than *SR*8-2. Current feeding into the point of emergence of the stroke from both directions raised the conductor to flashover potential at both towers. Only 10,000 amperes stroke current or 5,000 amperes conductor current were required. Flashover by lightning stroke current was followed by short-circuit power current, and trip-out resulted. This case is typical of measurement results obtained for strokes to a conductor.

Case III—Stroke to a Tower With Ground Wires. The case of a direct stroke to a tower of a line equipped with overhead ground wires is very much the same as without ground wires, especially when tower footing resistances are low. The ground wire, of course, assists in holding down the tower potential at the stroke. The current flowing into the stroke feeds in through the ground wire from both directions as well as up through the tower structure. As a result, the resistance drop at the tower footing is reduced in proportion to this decrease in tower footing current. Assuming a surge impedance of 250 ohms in both directions for the ground wire and a footing resistance of 50 ohms, the ground wire will carry a portion of the total stroke current at least as great as the inverse ratios of these resistances. The more slowly the feed-in current to the stroke builds up, the greater will be the portion of current carried by the ground wire. It is believed that in many cases these ground wire currents are very much higher than might be indicated by comparison of ground wire surge impedance and footing resistance at the tower struck. In other words, the ground wire serves effectively in holding down structure potentials because it provides for the feeding in of stroke current through several adjacent tower footings.

Table VI—Field Record Illustrating Direct Stroke to a Tower. With Ground Wire Present

Glenlyn-Roanoke 132 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current(A) Amp.	Tower Potential Kv	Expulsion Protective Gap Operations Circuit No. 1	Trip-Outs
78*R*	12	−16,600	200	Top phase	
79*R*	12	−66,000	790	All 3 phases	Circuit 2
80*R*	5	−36,000	180	Top phase	

A indicates data recorded by instruments located as shown on Fig. 2.

A specimen field record obtained during 1934 from the Glenlyn-Roanoke line pertaining to this case is given in table VI.

Towers adjacent to the consecutive towers listed in the table showed no evidence of having participated in the disturbance. The stroke was located at tower 79*R* and tower potential at this structure was high enough to operate all 3 expulsion protective gaps[13] on circuit 1, and to flash over insulators on circuit 2. The gaps prevented an outage on circuit 1. On circuit 2 at least one insulator assembly of a

10 unit string flashed over, trip-out of this circuit resulting. The 1×5 microsecond wave flashover for 10 units is 920 kv and the $1^1/_2 \times 40$ microsecond wave flashover is 820 kv. As the tower potential was 790 kv, a very slow wave is indicated. The lightning currents feeding in over the ground wire and the flashed conductors divided in adjacent towers about inversely as footing resistances.

Case IV—Stroke to Ground Wire. A stroke building up from near mid-point on the ground wire is fed by currents flowing in from both directions. Here the potential of the ground wire will be something less than $^1/_2$ the stroke current times the surge impedance of the ground wire. Reflections returning from adjacent tower footings where resistance is low will act to hold down ground wire potential, and more effectively the slower the building up of current feeding into the stroke. The effectiveness of conventionally spaced ground wires in reducing insulator flashovers has long been recognized. Many strokes have built up from these wires and flashover to line conductors has apparently not occurred. This is in spite of the fact that a value of 50,000 amperes is reasonable for many strokes. One-half this current with a 500 ohm surge impedance and no reflections would give a ground wire potential in excess of 12 million volts. Some coupling effect with the line conductors would, of course, reduce the insulator stress below this value. The inference, however, that ground wire potentials are effectively reduced by reflections from adjacent tower footings before flashover voltages to the conductors are reached appears inescapable. Only one microsecond is required for the returned reflection in the extreme case of 1,000 foot tower spans. A record of a specimen mid-span stroke to a ground wire on the Glenlyn-Roanoke line during the 1933 season is shown in table VII.

Table VII—Field Record Illustrating Direct Stroke to a Ground Wire

Glenlyn-Roanoke 132 Kv Line

Tower Number	Footing Resistance Ohms	TowerCurrent(A)Amps.	Tower Potential Kv	Across-Tower Potential (B) Kv	Expulsion Protective Gap Operations Circuit No. 1	Trip-Outs
103*R*	4	−16,400	65	50	None	None
104*R*	13	−20,400	265	80	None	
105*R*	16	0	0	10	None	

A, *B* indicate data recorded by instruments located as shown on figure 2.

In this case the nearly equal division of current between towers 103*R* and 104*R* and the very similar across-tower potentials, point to a direct stroke at mid-span on the ground wire. The tower footing resistances were sufficiently low to hold down tower potentials below expulsion protective gap operation and insulator flashover. No disturbance to line operation resulted from this stroke and no line damage was traced to it. On a surge impedance basis, assuming 500 ohms for the ground wire, a current of 20,000 amperes should give a ground wire potential of 10 million volts, sufficient potential to flash over to a conductor. Obviously, the rate of current rise was slow enough to permit repeated reflections from tower footing to eliminate to a considerable extent the surge impedance of the ground wire.

The Counterpoise (Buried Ground Wire)

The most significant way in which the counterpoise functions to prevent line flashover is by reducing current density in the earth at the tower base. In this way the voltage drop at the tower base is reduced and the tower structure is held down to values below insulator flashover.

An excellent record illustrating the functioning of the counterpoise was obtained on the Wallenpaupack-Siegfried line during 1934. The record is shown in table VIII.

The stroke is assumed to have built up from the overhead ground wire near tower *WT*12-3. The concentration of the tower leg currents at the tower side connected to the counterpoise is quite evident. Figure 1 shows how the counterpoise is connected to the legs at these towers. Before the installation of the counterpoise 3 of these tower footing resistances were approximately 80 ohms, a value which with the current shown in table VIII would give tower potentials well over insulation flashover. The across-tower potentials were low. Apparently no flashovers occurred between the overhead ground wire and conductors, even though large currents flowed from tower to tower and the ground wires were but 16 feet away from the line conductors.

Effective Location of Overhead Ground Wires

In table IX is summarized a comparison of faults on double circuit lines on 2 systems, that of the Victoria Falls and Transvaal Power Company, South Africa,[14] and that of the New York Power and Light Corporation. Following is a brief description of these lines. The Victoria Falls line is 63.5 miles long of double circuit. The spacing between conductors in each circuit is 12 feet and the horizontal distance between circuits is 23 feet. There is one center ground wire 18 feet above the top conductors. The record for this line in table IX is for the 8 years, 1926 to 1933, inclusive. In 1930, 2 additional ground wires were attached to the top cross arm of towers 120 to 140 inclusive, one over each circuit. Also, in the same year, one additional ground wire was attached to the top cross arm over the South circuit on towers 141 to 164, inclusive. The additional ground wire or wires covered about 12.5 per cent of the total number of towers, which is 361. The insulation of these lines consists of 9 disks having a dry flashover of 350 kv root mean square in suspension, and 11 disks with a dry flashover of 420 kv root mean square in strain. These are equivalent to about 6 and 7 $5^3/_4$ inch disks, respectively.

The New York Power and Light Corporation por-

tion of table IX covers 8 110 kv double circuit lines, a total of 316 miles. The spacing between conductors varies from 8 to 13 feet and the horizontal spacing between circuits from 17 to 28 feet. 98 miles of line have one central ground wire 8 feet above the top conductor. The remaining 218 miles have 2 ground wires 7 and 8 feet above the top conductor and 20 to 36 inches apart. The record is for the better part of 4 lightning seasons, beginning June 1931 and ending July 1934. The insulation on these lines consists of 7 to 11 disks.

It will be noted that the double circuit faults on both sets of lines tend to be fairly even on top, middle, and bottom conductors. The single circuit faults, however, are very high on the top conductor, lower on the middle, and lowest on the bottom for the Victoria Falls line; while for the New York Power and Light Corporation line the single circuit faults are highest on the bottom conductor and lowest on the top conductor.

These figures indicate fairly good shielding on the New York Power and Light Corporation line and poor shielding on the Victoria Falls line. The majority of the single circuit faults are probably due to strokes making direct contact with the conductors. On the Victoria Falls line the major portion has only one ground wire. Many strokes evade the ground wire and make contact with the conductors, especially the top conductor. The high ground wire has poor coupling with the conductors and gives poor induced stroke protection.

On the New York Power and Light Corporation lines the ground wires are closer to the conductors. The coupling with the conductors is good and the induced stroke protection good. This arrangement is effective in reducing direct strokes to the conductors, particularly to the top conductor. Most of the flashovers involve more than one conductor and both circuits, and the numbers on top, middle, and bottom conductors tend to average up.

It is essential in order to protect such double circuit lines to have 2 overhead ground wires, 1 over the conductors of each circuit, in order to prevent direct contact of the stroke with the conductors. Heights of 10 to 15 feet above the top conductor at the towers seem to be ample, based upon practical experience.

For prevention of flashover when the stroke makes contact with the ground wire or tower top, the tower footing resistance must be low, so that the product of the lightning current in the tower and footing resistance will not exceed the insulator flashover. On the Pennsylvania Power and Light Company's 220 kv line the critical resistance is about 12 ohms, and on the South African 132 kv line[14] the critical resistance appears to be about 7 ohms.

For single-circuit horizontally arranged lines 2 ground wires are usually installed, placed midway between the vertical planes through middle and outside conductors, or in some cases near the outside conductors. These appear to shield the conductors from direct contact with the stroke, and if the footing resistance is low enough, flashover is prevented in case of contact with the ground wire or tower. Ground wires 10 to 20 feet above the conductors at the towers appear to be amply high, based upon operating experience.

For lines without overhead ground wires, the stroke usually hits the conductor between towers and flashover nearly always results. The tower footing resistance has no effect on flashover in such cases except where the stroke makes contact with the tower. It is almost hopeless to try to prevent flashover of such a line, unless some auxiliary means are used, such as expulsion protective gaps.

Table VIII—Field Data Illustrating Effect of Counterpoise on Distribution of Direct Stroke Current in Tower Legs

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Tower Footing Resistance, Ohms	Tower Leg Currents (A): Legs Connected to Counterpoise, Amp.	Tower Leg Currents (A): Free Legs, Amps.	Across-Tower Potential (B) Kv	Remarks
WT11–5	1.4	− 2,200	0	None	No trip-
WT12–1	1.4	− 12,200	− 3,500	16	out or
WT12–2	1.4	− 13,900	− 4,000	16	damage
WT12–3	1.4	− 24,400	−14,300	64	to the line
WT12–4	1.3	− 5,400	− 1,000	None	resulted
WT12–5	1.7	− 18,900	− 3,200	6	from this
WT12–6	1.4	− 2,300	0	14	stroke
		− 79,300	−26,000		
		− 26,000			
		−105,300	Total stroke current		

A, B indicate data recorded by instruments located as shown on figure 1. Figure 1 shows how the counterpoise is connected to the legs at the above towers.

Table IX—Single and Double Circuit Faults

Victoria Falls and Transvaal Power Company (132 Kv) and New York Power and Light Corporation (110 Kv) Transmission Lines

Conductor	Victoria Falls: Single Circuit	Victoria Falls: Double Circuit	New York Power and Light: Single Circuit	New York Power and Light: Double Circuit
Top	43	26	8	41
Middle	17	30	12	38
Bottom	13	32	13	36
Total	73	88	33	115

Victoria Falls and Transvaal Power Company data from 63.5 miles of double circuit line. Eight years record from 1926 to 1933, inclusive.

New York Power and Light Corporation data from 316 miles of double circuit line. Three and one-half years record from 1931 to 1934.

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Firing Time of an Igniter Type of Tube

The time interval required for ignition or "firing" of an igniter type of rectifier tube is found to vary in a statistically systematic manner between successive operations. When in continuous operation with igniter rod potential gradients greater than a critical value the median firing time is an inverse exponential function of the gradient in the rod. If the gradient be reduced gradually below the critical value the firing time rapidly approaches infinity, corresponding to failure to ignite at all. Temperature rise of the rod caused by continuous operation of the tube results in a marked reduction in resistance, critical gradient, and median firing time.

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TO THOSE engaged or interested in the development of the igniter type of mercury rectifier tube or in its applications, it may be useful to know how much time may be expected to elapse between the application of the initiating impulse to the igniter rod of the tube and the establishment of the arc between cathode and anode, and how this time is affected by conditions of operation. The cathode ray oscillograph measurements here described have shown that an ignition time of the order of a few microseconds ordinarily may be expected, but that it varies over a rather wide range for moderate and low impulse gradients along the igniter rod.

A Westinghouse tube, type *KU*-637, having a continuous average current rating of 5 amperes with convection cooling, 20 amperes if fan-cooled, and a surge current rating of 1,000 amperes, was used for the tests. It is of glass and metal construction, of the general shape illustrated by figure 1. The over-all length is about 12 inches and the diameter 5 inches. There are 3 electrodes: a graphite anode at the top, a mercury pool cathode at the bottom, and an igniter rod, of carborundum or similar material, the lower end of the rod being immersed in the pool to a depth of a few millimeters. The rod of the particular tube used has a d-c resistance of 80 ohms when cold and 20 to 40 ohms when heated by continuous operation. Its length between the supporting bracket and mercury level is 23 millimeters, and its diameter about 3 millimeters; it tapers to a point at the lower end, but most of the tapered length is immersed so that the diameter is practically constant over the length external to the mercury.

In evaluating the results of these tests it must be recognized, of course, that the particular tube used was one of the earlier ones of its kind (it was received in March 1934) and that manufacturing details probably have changed since that time, although the principles of construction and operation are the same. The quantitative results here reported apply, of course, only to the particular geometry and materials used in the tube tested, but the results should be helpful in interpreting the behavior of other tubes having principles of operation similar to this one.

For the particular tube used:

1. The only time element of importance in the ignition process is that between application of the voltage impulse and the initiation of an arc between the mercury pool and the bracket holding the rod. The arc between cathode and anode forms immediately, closing the anode circuit in a small fraction of a microsecond after the arc first strikes to the bracket.

2. The time required for the arc to strike to the bracket varies from cycle to cycle, the variations following a simple statistical law.

3. When in continuous operation with igniter rod potential gradients greater than a critical value (about 85 volts per centimeter in these tests) the median time varies as an inverse exponential function of the voltage gradient in the rod; one series of tests indicates a median time of $1^1/_2$ microseconds and another about 3 times that for a gradient of 150 volts per centimeter.

4. As the rod gradient is reduced below the critical value the median time required for ignition rises rapidly, but not abruptly, toward an infinite value corresponding to failure to fire at all.

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2. For all numbered references see list at end of paper.

5. Because the shift between the nonfiring condition and that of a finite median firing time is not an abrupt one, the phase position at which ignition occurs in response to a gradually growing igniter-rod voltage, such as a 60 cycle sine wave, should vary from cycle to cycle, as it does in fact.

6. The resistance of the rod, the critical gradient, and the median firing time for a given gradient all decrease substantially as the tube and the rod heat up in continuous a-c operation. The rod resistance and critical gradient decrease to about $^1/_2$ to $^1/_3$ of the cold values, and it seems likely that the logarithm of the median critical-gradient firing time decreases in a similar ratio.

7. The statistical nature of the time relation leads to intermittent operation, that is, occasional failure to ignite at all, if the rod gradient be small or of very short duration. For any given igniting circuit it should be possible to calculate the per cent flicker if the statistical law governing the rod behavior be known, and also to predict the extent of time variation in ignition. With rod gradients in the neighborhood of 150 volts per centimeter the probability of flicker is extraordinarily small if the duration of the firing impulse is as much as 10 or 15 microseconds.

8. With rod gradients in the neighborhood of 300 volts per centimeter, the lower limit of time for ignition, and therefore the minimum energy required for ignition, is determined by the relative values of resistance and inductance in the igniting circuit.

9. If very prompt ignition be desired, either to reduce energy demand or for other reasons, it is necessary to keep the inductance of the igniting circuit small, that is, a matter of a few microhenries, the upper limit depending on the resistance of the igniting circuit and the speed of response wanted.

10. Ignition occurs satisfactorily with connections to the mercury pool and the bracket reversed, the bracket then serving as the cathode. No time tests were made with these reversed connections.

11. The results of these measurements, together with tests made by others on backfires in mercury rectifiers[2] and reignition of a-c atmospheric arcs,[3] suggest the existence of a statistical type of relation between ignition time and gradient for any spark or arc kindling process. In the present study the microscopic effects of mercury level variation must contribute to the statistical variability of firing time; but it is not at all certain that this is an important cause of the time variations, because indirect evidence suggests statistical behavior when the arc originates between the rod and the fixed metal bracket.

Ignition Process

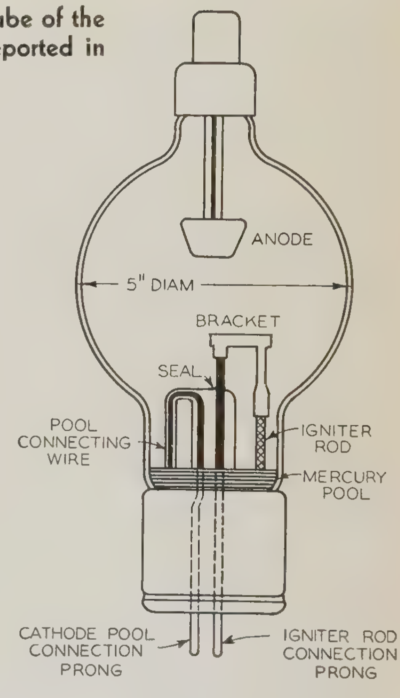
Ignition of the arc within the tube depends on the existence of a considerable potential gradient in the rod at the junction with the mercury surface. It consists of 2 distinct operations: one the initiation of an arc between the cathode pool of mercury and the metal bracket that supports the rod, the other the establishment of the arc path to the anode. Test results show that the only appreciable time element is that between the application of voltage to the rod and the initiation of the arc from the mercury pool to the bracket.

Tiny sparks can be observed at the junction of the mercury and igniter rod when the gradient is almost but not quite large enough to initiate the arc. Even when the gradient is produced by a steady direct current these sparks dodge erratically about the rod-mercury junction. As the gradient becomes larger the sparks become less yellow and more brilliantly white, until finally an arc forms at the junction. The lower terminal of this arc, a hot spot cathode, moves away from the rod along the surface of the pool, while the upper terminal travels upward along the rod with extreme rapidity; when it reaches the metal of the supporting bracket the rod of course is short-circuited by the arc. Ignition of this arc across the rod occurs with current in either direction; if the upper end of the rod be the more negative terminal the arc originates there, the cathode moving away from the rod along the metal of the bracket, and the other end of the arc traveling rapidly down the rod to form an anode on the mercury pool. If voltage impulses be applied to the igniter rod with the anode disconnected, these formations along the rod and bracket easily may be observed. With reverse gradients almost sufficient for ignition the same kind of erratically dodging sparks appear at the junction of the rod with the fixed metal of the bracket as those normally observed at the junction with the slightly agitated mercury pool surface; movements of the liquid at the junction cannot be considered the controlling influence in the shifting of the sparks.

Test Procedure

During the tests for determining the time required for ignition the tube was operated continuously on alternating current, with an average current of about half the normal rating. The circuit arrangement, illustrated in figure 2, was designed primarily for convenience in applying an igniting impulse of controllable magnitude and phase position. During

Fig. 1. A 2.5 ampere tube of the type used in the tests reported in this paper



each half cycle in which the anode is negative the capacitor of the igniting circuit is charged through the mercury rectifier tube to the peak of the 440 volt wave (see figure 3). The grid of the grid-controlled gas-filled rectifier tube swings positive at some controllable moment in the succeeding positive half cycle; the grid-controlled tube becomes conducting at once so that capacitor potential appears across the noninductive resistor and igniter rod in series. The potential gradient in the rod is determined by

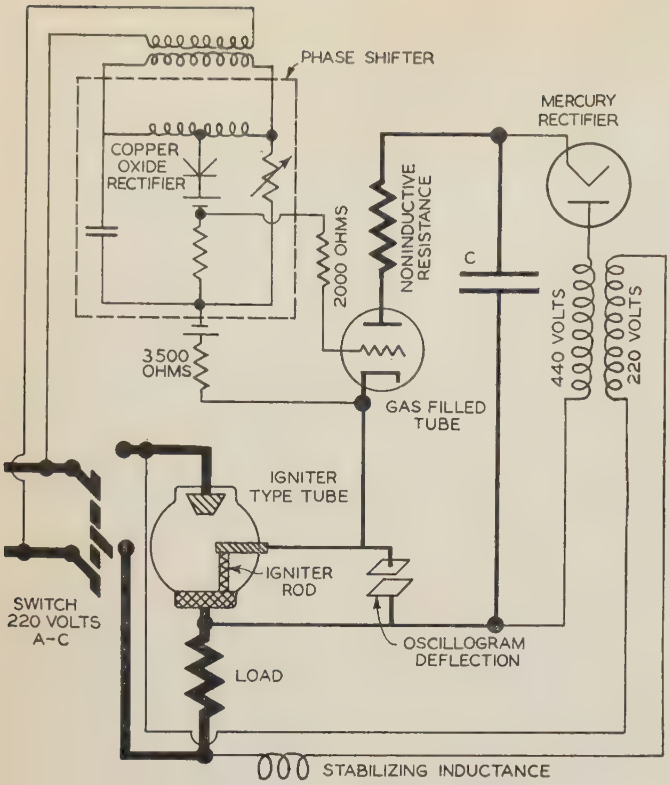


Fig. 2. Circuit for measuring ignition time

the proportioning of these 2 resistances; with sufficient gradient, ignition occurs.

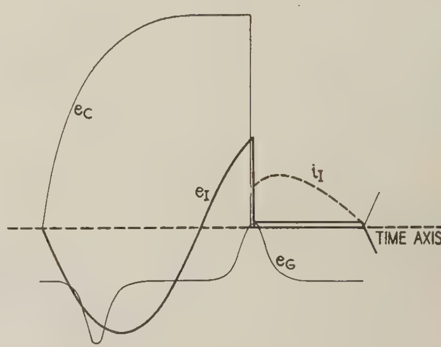
After ignition the arc drop between cathode and anode is small and approximately constant; current flow continues until the end of the positive half cycle, when the sequence begins again. A small stabilizing inductance in the power supply to the igniting circuit helped to reduce flicker, possibly through its effect on transient interactions between load and igniting circuits at the moment of ignition. The phase shifter ordinarily was adjusted to cause ignition at about the peak of the positive half cycle. A peaked grid voltage was desired in order to insure a nonconducting state in the grid-controlled gas-filled tube at the beginning of each inverse half cycle; it was obtained by having the phase shifter battery charge through a copper oxide rectifier and a resistance; the voltage from the resistance was biased and applied to the controlling grid.

Oscillograms

Figure 4*A*, a slow-speed cathode-ray oscillogram, illustrates the over-all form of the condenser discharge current in the rod. Discharge was completed in a little more than 200 microseconds in the operation recorded by this oscillogram; the time varied for different values of capacitance and igniting circuit resistance. Figure 4*B* contains 3 high speed records of the rising portion of rod current, showing that it grows very rapidly to an intermediate value, hesitates there for a few microseconds, then proceeds upward to a maximum. The hesitation occurs at the current value determined by the combined resistance of the noninductive resistance and rod; the abrupt progression upward occurs when the arc strikes to the bracket, short circuiting the rod and permitting a larger current to flow. The useful function of the igniting circuit is completed as soon as the current starts to rise from the intermediate level. Such current records permit determination of the ignition time, but a more satisfactory measurement is obtainable from records of the voltage across the rod, illustrated by figure 4*C*. The rod voltage rises abruptly at the moment the grid-controlled tube discharges and vanishes abruptly when the bracket arc initiates, so that the duration and height of the rise in the rod voltage, as recorded by the oscillograph, measure the time required for ignition at a given voltage. Records of this kind were made at brief intervals, the tube remaining in continuous operation throughout entire sets of tests. The temperature of the base of the tube was recorded from time to time; it was found to remain practically constant for the duration of each series of observations. The oscillograph film was advanced slightly, and the position of the electron beam's trace shifted slightly, magnetically, between successive observations, giving rise to the type of record illustrated by figure 4*D*, each film accommodating many voltage traces.

Fig. 3. Cyclic variations of current and voltage

e_c = voltage across capacitor
e_i = voltage across igniter type tube
e_g = grid voltage of grid-controlled gas-filled rectifier tube
i_i = current in igniter type tube



The 3 separate voltage traces of figure 4*C* illustrate the variability of the ignition time. Although the rod voltage values for the 3 records are not markedly different, ignition took place in 1.1, 3.6, and 1.4 microseconds, respectively. Much larger variations in firing time occurred at lower ignition gradients; near a critical low value of gradient ignition often occurred after the trace passed beyond the limits of film exposure, and sometimes not at all, giving rise to flickering of the tube.

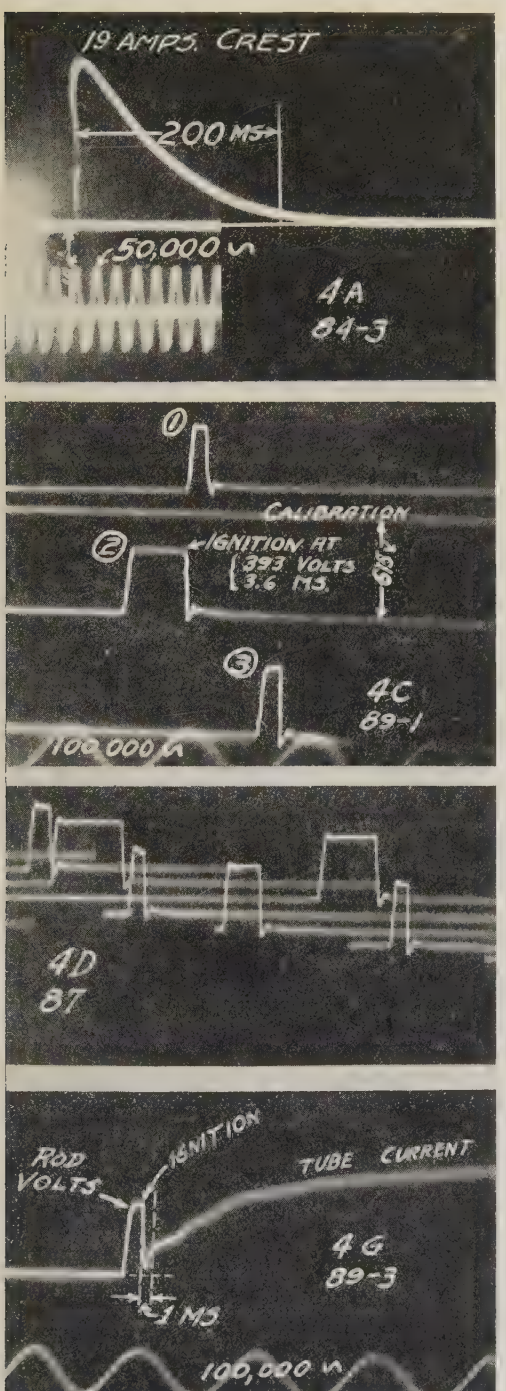
Figure 4*E* illustrates the extreme rapidity of the collapse of the voltage of the grid-controlled tube when the grid swings positive. The irregular oscillations after collapse probably are caused by successive reflections in the lead-in wires to the oscillograph plates. Figure 4*F* is an oscillogram similar to figure 4*C* (rod voltage) except that the lead-in circuit was highly oscillatory and the resistance in series with the igniter rod slightly inductive. Both of these conditions had to be corrected before satisfactory measurements could be made. The frequency of the oscillations of figure 4*F* agrees approximately with the value calculated from the length and construction of the oscillograph lead-in circuit, and the relatively slow

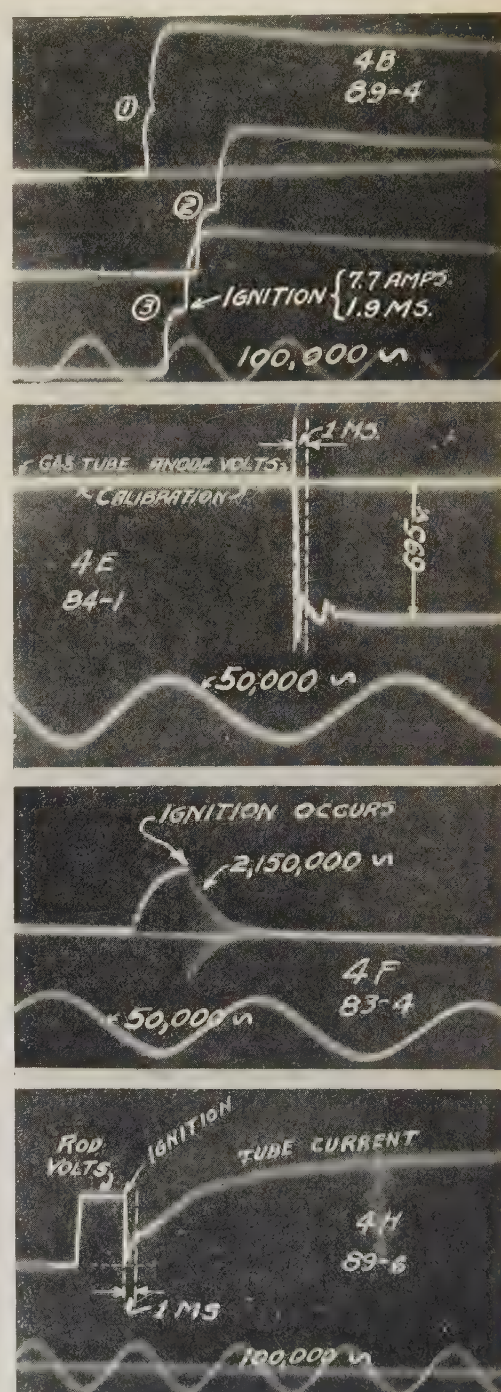
rate of rise of the igniter rod voltage with the inductance of the resistance as estimated from its dimensions.

The rapidity of the transfer of the arc from the bracket to the anode is indicated by figures 4*G* and 4*H*, oscillograms that measure simultaneously the igniter rod voltage and the anode current. The rod voltage was brought to the electrostatic deflection plates, and the anode current was passed through a magnetic deflecting coil on the oscillograph. Since anode current is zero before ignition, and rod voltage practically zero after ignition, the 2 measurements do not conflict. The anode current, measured by the slowly rising portion of the trace, begins in much less than a microsecond after the rod voltage begins to drop. The gradual rather than abrupt increase of anode current is caused by the presence of a little inductance in the load circuit.

Statistical Variations in Ignition Time

Values of the noninductive resistance were calculated to give approximately 450, 350, 250, and 200 volts on the igniter rod, and a series of records was made with each value of resistance. The resulting over-all range of ignition time observed was from a few tenths of a microsecond to 90 microseconds. The igniter rod voltage varied to some





A (left). Slow speed oscillogram showing rise and fall of current in igniter rod circuit; *MS* signifies microseconds

B (right). Three high speed oscillograms of the rise of current in igniter rod circuit; ignition occurs at: (1) 7.4 amperes, 0.5 microseconds; (2) 7.7 amperes, 1.4 microsecond; (3) 7.7 amperes, 1.3 microseconds

C (left). Three oscillograms of igniter rod voltage, showing ignition at: (1) 376 volts, 1.1 microseconds; (2) 393 volts, 3.6 microseconds; (3) 435 volts, 1.4 microseconds

E (right). Collapse of plate voltage in the grid-controlled gas-filled rectifier tube of figure 2

D (left). Portion of film 87, showing method of accommodating many traces on a film

F (right). Igniter rod voltage, similar to C but with oscillatory lead-in circuit to deflecting plates of oscillograph and appreciable inductance in ignition circuit

G (left). Simultaneous record of igniter rod voltage and tube current, showing rapidity of establishment of arc path to the anode

H (right). Similar to G

Fig. 4. Cathode ray oscillograms, typical of those upon which the results presented in this paper are based

extent within each series, possibly as a result of changes in the resistance of the rod resulting from inconstant temperature. The temperature measured by a thermometer in contact with the base of the tube just outside the pool changed very little, but there may have been variations of temperature distribution within the tube. Average values of rod voltages as measured from the oscillograms were 453, 377, 276, and 198 volts for the 4 series (recorded on oscillograph films 86 and 87).

Figure 5 shows the results of the 453 and 198 volt series of tests; not all of the lower voltage observations are indicated, for in some instances ignition occurred beyond the limit of the time scale used in the figure. Both these sets of observations were made with a capacitance of 4 microfarads in the ignition circuit. The series resistance in the rod circuit was 54 ohms for the lower voltage points and 18 ohms for the higher voltage points. It is evident that (1) the higher voltage favors early firing, and (2) at each voltage the time required is variable. Similar variability of time required for ignition of an arc has been observed in mercury rectifiers[2] and in the reignition of a-c atmospheric arcs.[3] All this suggests the existence of a statistical type of relation between ignition time and gradient for any spark or arc kindling process.

Suppose pdt is the probability of ignition within a differential time interval dt, p being primarily a function of igniting gradient. If P be the probability that ignition occurs later than t seconds after application of gradient,

$$-dP = P \cdot pdt \tag{1}$$

or

$$-d \log P = pdt \tag{1a}$$

for the chance of ignition occurring at *some* time later than t is by definition P, and the chance of ignition in the particular interval dt *immediately following* t is pdt; their product, $P \cdot pdt$, is the chance that ignition will not occur until t seconds have passed, but will occur in dt seconds immediately thereafter. This is of course the negative differential change in P, negative because P must become

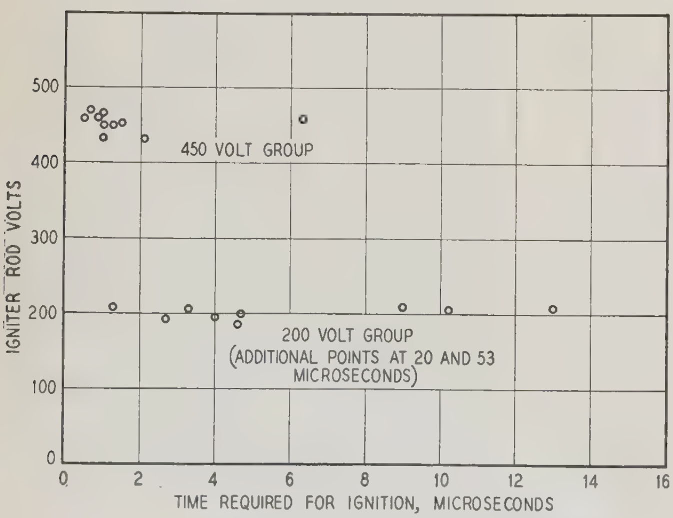


Fig. 5. Variability of time required for ignition

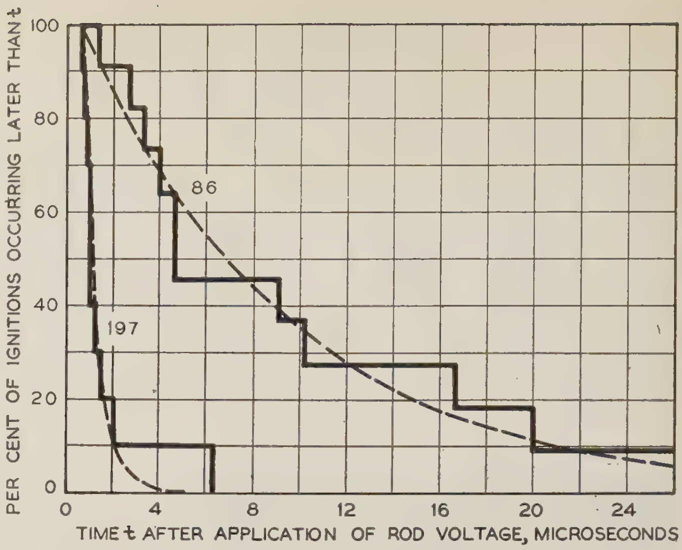


Fig. 6. Per cent of ignitions occurring later than time t, with rod gradients of 86 and 197 volts per centimeter (films 86 and 87)

less for longer times. The solution for P, approached in a slightly different manner by Slepian and Ludwig,[2] is of course

$$P = \epsilon^{-pt} \tag{2}$$

if p be independent of time, and

$$P = \epsilon^{-\int_0^t pdt} \tag{3}$$

if p be a function of time. In deriving these forms it is recognized that $P = 1$ when $t = 0$.

If it be assumed as a first approximation that the probability of firing in a very brief interval of time is dependent only on the magnitude of the rod gradient and not on its duration, the distribution of points for each voltage group in figure 5 should be approximately representable in a manner suggested by equation 2. Graphical representation of the observed distribution is accomplished by determining for each moment of time the ratio m/M, where m is the number of observations requiring longer than that time for ignition, and M the total number of observations at that voltage. If the number of observations be finite, such treatment produces a stepped line rather than a smooth curve. Two such stepped lines appear in figure 6, for the 2 voltages of figure 5; the same data with 2 additional intermediate voltages are plotted to an inverse logarithmic vertical scale in figure 7. The stepped lines converge at a point slightly to the right of where $t = 0$, for in spite of precautions taken the igniting circuit contained enough inductance to make the rise of the rod voltage require an appreciable fraction of a microsecond, and time was measured from the beginning of the rise.

The time distribution described by the stepped lines of figures 6 and 7 can be well approximated by an empirical relation of the form

$$p = \frac{1}{t_0} \epsilon^{F/F_0} \tag{4}$$

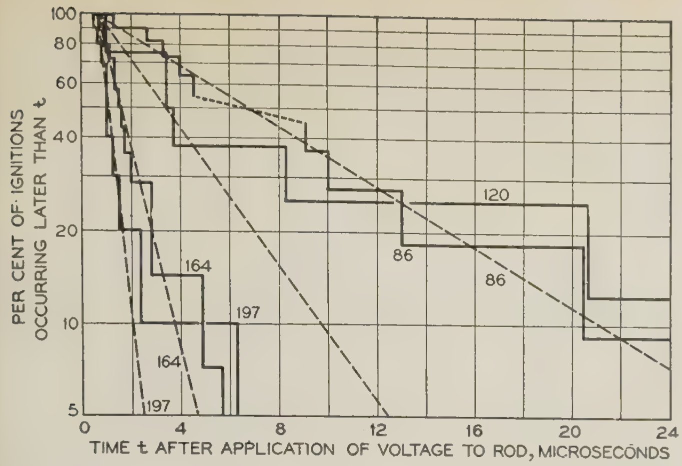


Fig. 7. Per cent of ignitions occurring later than time t; logarithmic per cent scale. Potential gradients 86, 120, 164, and 197 volts per centimeter (films 86 and 87)

giving

$$\log_e P = -\frac{t}{t_0}\epsilon^{F/F_0} \tag{5}$$

where F is the voltage gradient along the rod in volts per centimeter, and t_0 and F_0 empirical constants. The dotted lines on the figures represent this empirical relation, time being measured from an effective or equivalent zero placed 0.65 microsecond from the left of the figure, and t_0 and F_0 having the values 72 microseconds and 41 volts per centimeter. The dotted lines are straight or curved rather than stepped because they represent the behavior to be expected from a great many observations. In judging the correspondence between the stepped and empirical curves it must be borne in mind that there were relatively few (8 to 19) observations in each group, so that very close correspondence would be a remarkable accident. The agreement is quite satisfactory except for the series taken with a gradient of 120 volts per centimeter. This particular series included fewer observations than any of the others and appears, even on the basis of a cursory inspection of the data, to be unrepresentative.

Figure 8 represents the behavior in a subsequent series of tests (recorded on film 88) for which the ignition times were substantially longer than for those leading to figures 6 and 7. Zero time adjustment (1.2 microseconds) was made before preparing the figure. Records of the voltage calibration corresponding to figure 8 were destroyed accidentally after the first measurements were made from the oscillograms, so that it has not been possible to make a positive subsequent check of the gradient magnitudes; but the weight of evidence, based partly upon relative time and voltage sensitivities of the oscillograph, appears to justify the correctness of the values marked. If they are correct, the change in the median time by a ratio of about 3 to 1 between figures 7 and 8 must be attributed to variations in ambient temperature or duty cycle of the tube. The resistance of the rod is quite sensitive to operating conditions and may affect the ignition time. The 3 voltage groups of figure 8 seem to be consistent with each other in that they follow the same kind of a law as those of figure 7, the empirical constants being 195 microseconds and 45 volts per centimeter.

Median Time Versus Rod Gradient

Equation 5 can be adapted to express the median ignition time t_m as a function of the rod gradient by letting $P = {}^1/_2$, as follows:

$$t_m = t_0\epsilon^{-F/F_0}\log_e 2 \tag{6}$$

$$= 0.693t_0\epsilon^{-F/F_0} \tag{7}$$

This form lends itself well to representation of the median time on a logarithmic scale, as in figure 9. The 7 points circled there mark median times selected by drawing the best straight lines through the original logarithmic stepped curves (figures 7 and 8) prior to the selection of any empirical law and the solid lines drawn through the points represent the corresponding general relation between voltage gradient and median time. With the one exception of the series at 120 volts per centimeter, discussed earlier, these median times fit an exponential law very well indeed; there is no uncertainty at all as to the placement of either of the 2 heavy lines. Various other types of relationship between voltage gradient and median time were tested, but the exponential law fits the data much better than any other besides being in agreement with the relationship found by Slepian and Ludwig[2] to exist between back-fire frequency and voltage in mercury rectifiers, a somewhat similar physical situation.

The curves of figure 9 also describe the variations in the reciprocal of p, the momentary ignition probability, for combining equations 4 and 6,

$$\frac{1}{p} = \frac{t_m}{0.693} \tag{8}$$

The significance of the constants F_0 and t_0 appears from a study of these curves in the light of equation

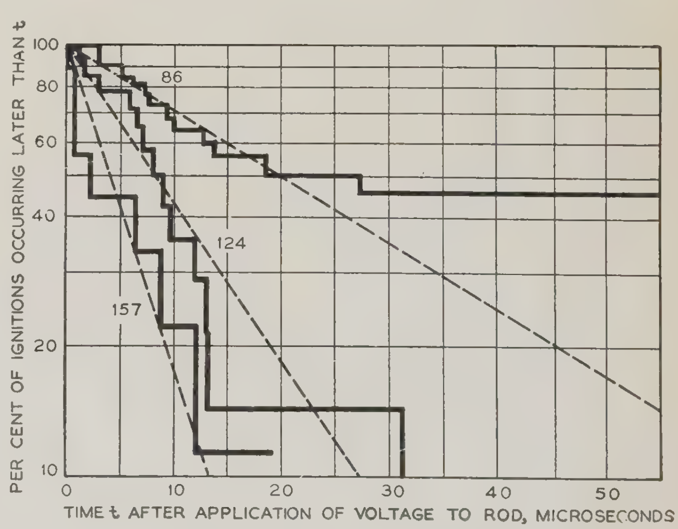


Fig. 8. Per cent of ignitions occurring later than time t; logarithmic per cent scale. Potential gradients 86, 124, and 157 volts per centimeter (film 88)

6; F_0 is the reciprocal of the slope of the straight line through the observed median times, and t_0 is proportional by the factor 0.693 to the median time expected at zero gradient if the empirical law were still valid there.

It is interesting to observe that the slopes are nearly the same for the 2 contrasting sets of observations. In a complete and correct theory F_0 probably would be independent of operating conditions. The 3-to-1 time factor between the 88 series and the 86–87 series probably is related to the fact, observed in the course of the tests, that after the rod became hot from continuous operation it would ignite at a much lower gradient than when cold, besides having a much lower resistance. Resistance and required gradient when hot were both between $^1/_3$ and $^1/_2$ of their values when cold.

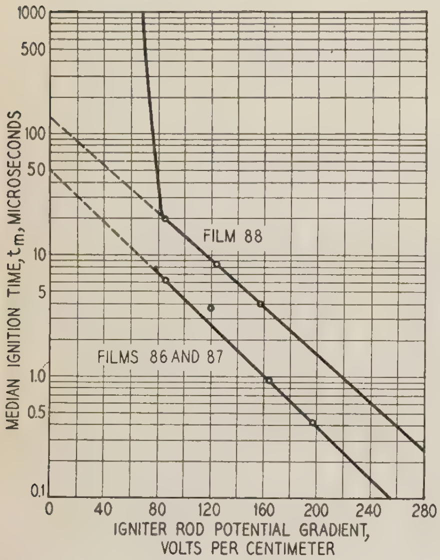


Fig. 9. Dependence of median ignition time on rod potential gradient

Energy Required for Ignition

The median time becomes very short as the voltage rises—so short in fact that for rod gradients in the neighborhood of 300 volts per centimeter the median time delay after establishment of the gradient but prior to ignition is small relative to the time required to build up the required rod voltage, even though the inductance of the igniting circuit is very small. For example, with a gradient of 300 volts per centimeter and igniting circuit resistance and inductance values of 40 ohms and 10 microhenries, it would require a little more than $^1/_2$ microsecond for the gradient to reach 90 per cent of its final value. Yet according to films 86 and 87 the median ignition delay at that gradient should be only $^1/_{30}$ microsecond, and only about 1 in 35,000 ignitions should be delayed longer than $^1/_2$ microsecond after establishment of the gradient. For rapidly rising impulse gradients, then, the lower limit to the firing time is dependent on the rate at which current can be built up in the igniting circuit, and the energy required to establish the magnetic field in the inductance may be an important part of the total energy demanded for ignition. Furthermore, the extremely rapid transfer of the arc from the bracket to the anode suggests that once the cathode spot is initiated, its continuance is not dependent on continuing energy input by way of the igniting circuit.

Ignition at Low Rod Gradients

Equation 6 and figure 9 expose the fact that the empirical equations given can apply only when the rod gradient has a substantial value. The dotted extensions in figure 9 indicate absurdly small median times at low gradients, for example a matter of 20 to 50 microseconds at 40 volts per centimeter, whereas in fact that gradient can exist indefinitely without causing ignition. Actually the median time becomes rapidly larger in the 88 series as the gradient is reduced gradually from 85 to 80 volts per centimeter as indicated by increasingly marked flickering of the tube and ultimate failure to fire at all. It is conceivable that each one of the tiny sparks observed around the rod contributes a chance of ignition, the likelihood of a sufficiently intense spark occurring depending on voltage gradient in the rod, and that at sufficiently low gradient sparks do not occur at all.

An analytical approach to the behavior at low voltages may be made on the basis of the longest-time curve (86 volts per centimeter) of figure 8, which does not describe a linear logarithmic distribution except for very short times. This logarithmic stepped line and the corresponding straight dotted line are redrawn in figure 10 to a scale which takes in all of the observed ignition points of that series. The stepped line runs off to the right and ultimately becomes horizontal, for in many instances ignition did not occur at all. An empirical curve to fit these data also should become horizontal at some definite level corresponding to the likelihood of failure to ignite, thus specifying the amount of flicker to be expected. A representative dotted curve of the required type has been drawn in figure 10.

Frequency of flicker and the shape of the curve of figure 10 were related closely to constants of the igniting circuit, for whenever ignition was delayed more than a score or so microseconds there was in the circuit used an appreciable drop in the capacitor potential and so in rod gradient. The rate of decay was determined by the values of resistance and capacitance in the igniting circuit, that is,

$$F = F_1 \epsilon^{-t/(RC)} \tag{9}$$

The time constant RC was about 360 microseconds for the observations upon which figure 10 is based. Delayed ignition under such circumstances makes p, the momentary ignition probability, vary with time, necessitating analysis according to equation 3 rather than equation 2. In preparing the figures, the part of the upper median time curve (figure 9) that lies above and to the left of the bend was co-ordinated with the dotted curve on figure 10, by means of equation 9 and a graphical integration according to equation 3. That is, the upper line of figure 9 is drawn so as to predict a time distribution in accord

with the observed facts of delayed ignition and flicker as described by figure 10. In general, if the median time curve and the circuit constants be known the per cent flicker can be predicted in this way. The data upon which this analysis is based are insufficient to do more than suggest the general type and location of the upward swing to be expected in the median time curves. This upper part of the curve presumably governs the observed variability in the phase position of ignition for applications[1] in which the igniter rod voltage is always some definite fraction of the sinusoidal anode voltage.

It is conceivable, of course, that the momentary ignition probability p decreases with time regardless of decay of gradient, through some such mechanism as the building up of a deposit on the mercury surface by recurring sparks. Such behavior would account satisfactorily for the appearance of flicker at moderately low gradients, but it seems that even then a more or less well-defined critical gradient must exist. It is simpler to attribute the appearance of flicker to a gradual decrease in p that results from decay of capacitor potential and so of rod gradient.

Median Firing Time at Critical Gradient

Firing time can be expressed as a function of the excess of gradient above the critical value F_c, as follows:

$$\log_e P = -\frac{t}{t_1}\epsilon^{(F-F_c)/F_0} \qquad (10)$$

which is the same as equation 5 if

$$t_0 = t_1\epsilon^{F_c/F_0} \qquad (11)$$

Then also

$$t_m = 0.693 t_1\epsilon^{F_c/F_0}\epsilon^{-F/F_0} \qquad (12)$$

where $0.693t_1$ is the median time at the critical gradient, that is, $0.693t_1 = 22$ or 23 microseconds for the 88 series of figure 9. The critical gradient was not determined for the 86–87 series; it was less, but probably not a great deal less, than for the 88 series, as evidenced by the lower values to which rod gradient could be reduced before severe flicker set in. When the rod was cold the critical gradient was in the neighborhood of 300 volts per centimeter, and casual observations indicated a median time measurable in seconds rather than microseconds. All this suggests a relationship approaching a direct proportionality between the critical gradient and the logarithm of the median firing time for the critical gradient, but the evidence is suggestive only and is offered merely as a guide to further study.

Causes of Variability in Firing Time

It has been suggested that the agitation of the liquid mercury surface at the rod junction may be an important factor in causing the observed statistical variability in firing time. Such agitation certainly exists all of the time, and has at least 2 immediate effects: (1) a gross effect, that of varying the gradient in the rod as a whole because of increases and decreases in effective rod length; and (2) variations in microscopic details at the points of current transfer.

Certainly not more than ±10 per cent variation occurs regularly in effective rod length, corresponding to about ±2 millimeter change in liquid level. If the lines of figure 9 were to be considered as representing a nonstatistical relation between firing time and gradient for the mean liquid level, a ±10 per cent variation in effective length would scatter the observations made at 86 volts per centimeter of the 86–87 series between 4 and 8 microseconds with the greatest concentration of points near the median.

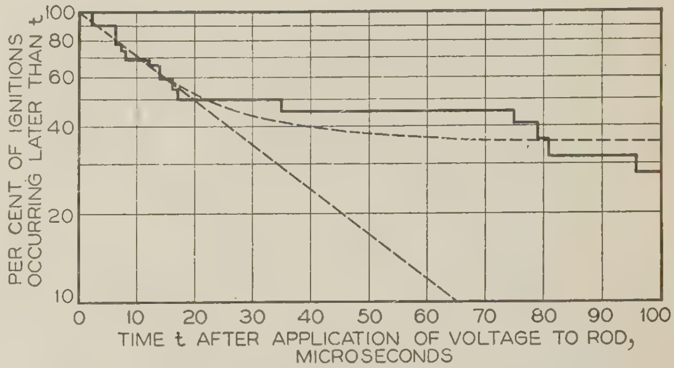


Fig. 10. Time distribution of ignition at a low rod gradient (86 volts per centimeter)

Actually 14 observations ranged between 1 and 50 microseconds with the concentration greatest near zero time. Neither the range nor type of statistical distribution accord with expectation if variability be attributed to the gross effect of variation in liquid level.

Effects of variations of mercury level on microscopic distribution of gradient, as between grains of the rod, is probably a contributing factor to the statistical nature of the results. The extent of the contribution could be estimated by oscillographic measurements with reversed rod polarity to determine firing time at the rod-bracket junction, where the geometry of the junction is fixed. No such tests were made, but there was qualitative similarity in operating behavior with normal and reverse polarity, as to magnitude of cold critical gradient, easily observed variability of time required for the rod to fire when cold, flicker when in steady operation near or slightly below the warm critical gradient, and spark behavior. There is enough such indirect qualitative evidence to require for the present the maintenance of an open mind as to whether or not variations in liquid level play an important part in causing statistical variations in firing time.

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An Electrostatic Audio Generator

Design and operating features of a multi-harmonic electrostatic audio frequency generator are described in this paper. The harmonics are generated singly by the rotation of a shielded segmented disk adjacent to a stationary wave pattern plate; the resulting changes in capacitance between disk and plate produce a sinusoidal charging and discharging current through an input resistance of a vacuum tube amplifier. Each harmonic is controlled independently in amplitude and in phase, and provisions are made for combining any 2 or more harmonics to obtain complex wave forms. Although designed specifically for psychological tests, the device should prove useful in any work requiring a flexible audio frequency supply of small capacity.

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PRODUCTION of current variations from definite periodic changes in capacitance is a relatively new approach to the old problem of tone or wave synthesis.[1–4] If a potential be applied across 2 parallel metal plates separated by a dielectric, the capacitance thus formed will become charged to $Q = CE$, where Q is the charge, C the capacitance of the plates, and E the potential across the plates. The expression for charging current, $i = dq/dt$, becomes $i = E\, dc/dt$ when the capacitance is caused to change by moving the plates. If the capacitance be given a definite periodic variation such as

$$c = \frac{1}{2}[C_0(1 + \sin \omega t)]$$

then

$$i = E\frac{dc}{dt}$$

$$= E\frac{d}{dt}\frac{1}{2}[C_0(1 + \sin \omega t)] = \frac{1}{2}E\, C_0\, \omega\cos \omega t]$$

A periodic variation in capacitance may be ob-tained by several methods. Perhaps the most di-rect method is that of rotating a segmented meta disk or drum relative to a designed fixed plate. I is possible to cause a capacitance variation also b simply rotating a segmented dielectric disk betweer 2 properly designed stationary metal plates. Rotat-ing steel disks are employed in the generator herei described. When, however, a sinusoidal capacitanc variation is desired, the problem resolves itself int one of constructing a specially shielded arrangemen with a suitable circuit so that the capacitance wi be directly porportional to the coincident area of th

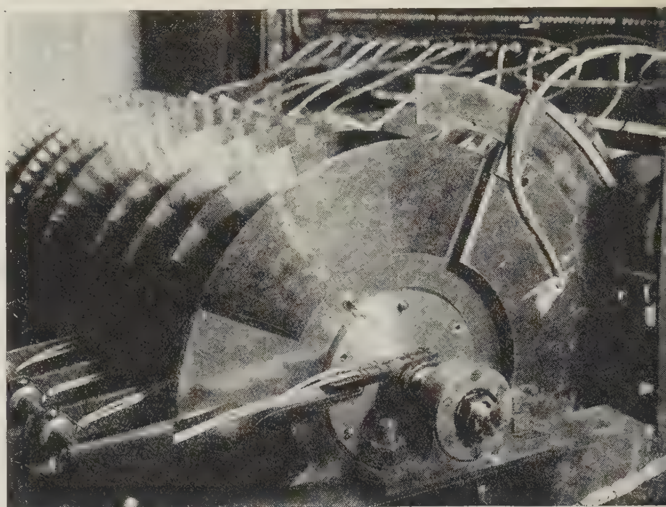


Fig. 1. End view of generator rotor showing revolving segments, one stationary wave-pattern-plate support, and portion of phase shifting arrangement

2 adjacent plates. The addition of resistance to th circuit and the possibility of fringing flux must b given consideration in the design.

Design Features

After a period of experimentation the author found a relatively simple arrangement that seeme to have a wide range of adaptability. Although th apparatus herein discussed was designed primaril for use in a psychological laboratory, it by no means i limited to this field. The following specification were assumed, to allow for maximum flexibility:

1. A sufficient current capacity to produce an audible tone.
2. The complex tone to include any or all of the first 16 harmonic
3. Each harmonic to be relatively free from stray component that is, it must be as nearly a pure sine wave as possible.
4. Individual magnitude control of each harmonic in 2 per cen steps.
5. A 360 degree individual phase control of each harmonic.

A paper recommended for publication by the A.I.E.E. committee on electr physics, and scheduled for discussion at the A.I.E.E. Great Lakes District mee ing, West Lafayette, Ind., Oct. 24–25, 1935. Manuscript submitted May 1 1935; released for publication July 8, 1935.

The authors wish to acknowledge the assistance of the following: Carl Seashore, Don Lewis, G. F. Corcoran, and J. L. Potter, all of The State Univer sity of Iowa, Iowa City.

1. For all numbered references see list at end of paper.

6. Arrangements for setting 5 wave forms in advance, so that tests may be made rapidly.

Rotor Construction. The circular rotating disks (see figure 1) are made of ground steel $^1/_{16}$ inch thick and are 15 inches in diameter. On each side of the disk is shellaced a layer of commercially manufactured heat insulating material made up of thin aluminum foil rolled smoothly and fastened to a layer of heavy paper; the paper insulates the foil from the steel disk. The segments were cut radially and every other one was removed before the shellac dried. For the fundamental frequency 6 segments are employed, 12 for the second harmonic, 18 for the third, etc. Each disk accommodates 2 harmonics, one on each side. The 8 disks are mounted on a one inch shaft which turns in 3 self-aligning ball bearing units. The rotor is driven by a $^1/_3$ horsepower synchronous motor. Any rate of rotation up to 2,400 rpm can be obtained by means of proper pulley or gear ratio.

Amplitude Control. The magnitudes of the waves, and thus the intensities of the individual harmonics, are controlled by varying the potentials on the rotating aluminum segments. Each segmented disk is connected to a slip ring. The carbon brushes bearing on these slip rings are connected directly to switch levers on a potential panel (see figure 2). The potential panel is made up of 50 resistances of 1,000 ohms each. Each resistance unit is connected between 2 of the 51 copper cross bars. The resistances may be seen on the back of the panel in figure 3. The total 50,000 ohm resistance bank is connected in series with a 50,000 ohm variable resistance and a continuous potential of 135 volts; 5 sliders are used for each harmonic. The switch levers are moved in tandem by a master lever at the right side of the panel as shown in figure 2. Arrangement is made to disconnect the input lead when the slider is in the lowest or zero potential position.

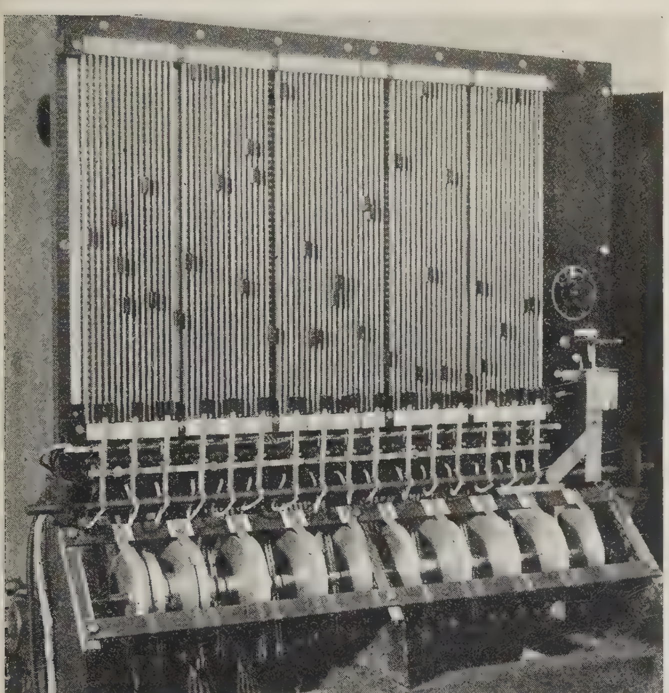


Fig. 2. Front view of generator showing amplitude control panel with sliders and switches, and phase control drums

Wave Pattern Plate. The wave pattern plate is designed so that when the rotating segments move parallel to it, the coincident area increases and decreases sinusoidally. This causes the capacitance between the plates to change in like manner.

Assume that the segments S of the rotor in figure 4 move over the parallel wave pattern plate P in the direction indicated by the arrow. When the segment S moves through a physical angle θ' one electrical cycle will be generated. Assume also that the current produced by rotating the segments in a plane parallel to P is to be $I_0 \sin \omega t$. Then in a simple series circuit with negligible resistance and with a constant potential E across the condenser plates P and S

$$i = \frac{dq}{dt} = E\frac{dc}{dt} = k_1 \frac{dA}{dt} = I_0 \sin \omega t$$

and therefore

$$\frac{dA}{dt} = k_2 \sin \omega t$$

or

$$\frac{dA}{dx} = k_3 \sin x$$

From the construction shown in figure 4,

$$\Delta A = \frac{y(\Delta x + \Delta x')}{2} \text{ (approximately)} \quad (1)$$

From similar triangles formed by the radial lines

$$R\Delta x' = \Delta x(R - y) \quad (2)$$

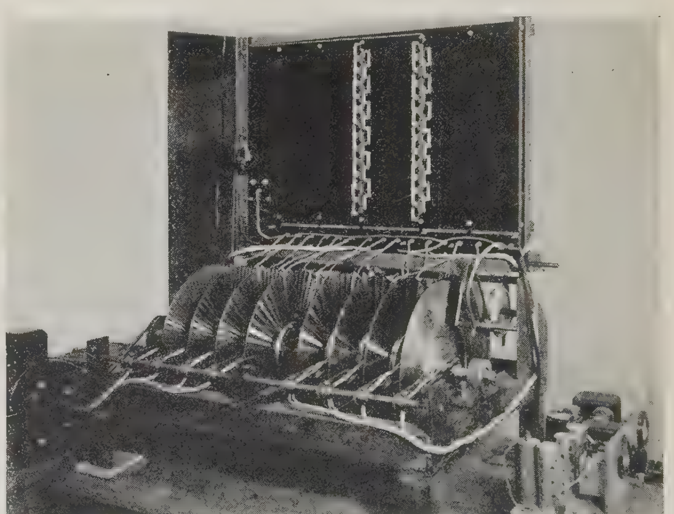


Fig. 3. Rear view of generator showing 50 1,000 ohm resistors, rotor, stationary plates, and brush and slip ring assembly. The amplifier is shown on the right and the synchronous driving motor on the left

Substituting the value for $\Delta x'$ from equation 2 into equation 1

$$\frac{\Delta A}{\Delta x} = y - \frac{y^2}{2R} \text{ (approximately)}$$

Then

$$\frac{dA}{dx} = y - \frac{y^2}{2R} = k_3 \sin x$$

Solving the resulting quadratic equation in y yields,

$$y = R - (R^2 - 2Rk_3 \sin x)^{1/2} \tag{3}$$

To determine k_3, or more conveniently $2Rk_3$, let x = 90 degrees. Then y reaches its maximum value, H, since $\sin x = 1$. Substituting these values in equation 3 gives

$$H = R - (R^2 - 2Rk_3)^{1/2}$$

from which

$$2Rk_3 = 2RH - H^2$$

Hence the final expression for y becomes

$$y = R - [R^2 - (2RH - H^2)\sin x]^{1/2} \tag{4}$$

(Expression for plate designs for use with rotating drums were developed by Culver,[2] and for inverted pattern plates by Lyon.[1]) The relationship between electrical and physical degrees is given by $x = \theta/S$, where θ represents the physical degrees and S the number of segments on the given rotor.

An example of the application of equation 4 to the design of the pattern plate for the second harmonic follows. The values used are: H = 2 inches, R = 6.75 inches, S = 12. The relationship between the electrical degrees, which were laid off on a dividing head, in terms of the physical degrees becomes

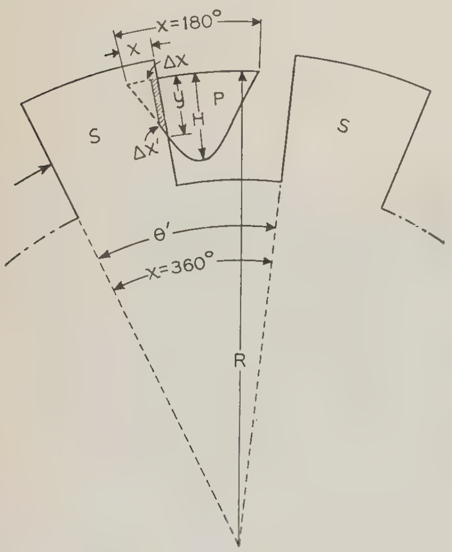


Fig. 4. Diagrammatic representation of the generating elements, for obtaining mathematical relationships

$\theta = x/S = x/12$. Values of y were calculated from equation 4 in steps of 10 degrees. The symmetry of the arrangement makes it unnecessary to compute any values of y for values of x greater than 90 electrical degrees. Figure 5 shows the actual shape of this plate as plotted from the data calculated.

Plate P is shellaced on a layer of paper insulation and mounted on a sheet iron support which is free to move for phase shifting. The sheet iron arc has a hole in the center to admit the connection of the conductor leading to the amplifier. Only one plate was necessary for each of the first 6 harmonic units. An average of 15 plates per unit was used for the remaining 10 higher harmonic units. The wave pattern plates for each unit were mounted on a single support. The use of multiple plates for the higher harmonics has 2 advantages: First, it reduces the effect of mechanical errors which increases when the segments and the plates become narrower; and second, the increased current output makes possible the use a lower input resistance which in turn reduces the distortion.

Phase Control. Phase displacement (see figure 1) is accomplished by moving the plate holder supporting the wave pattern along a circular arc. The motion is obtained by winding a cord on a hand operated drum located below the amplitude control panel (see figure 2). The physical angle of rotation varies from 60 degrees for the fundamental frequency to $3^3/_4$ degrees for the sixteenth harmonic while producing a change of 360 electrical degrees in each instance. For convenience and accuracy of adjustment the drums are varied in diameter so that about 290 degrees of rotation of each drum corresponds to 360 electrical degrees.

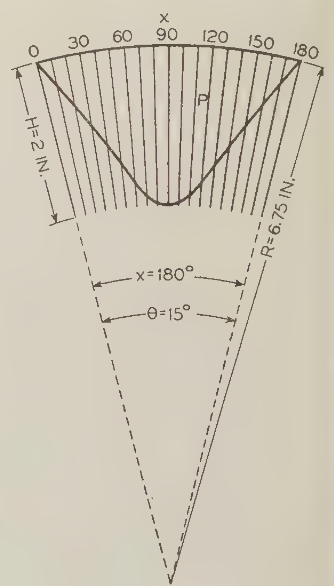


Fig. 5. Shape of sinusoidal wave pattern plate for second harmonic as obtained from equation 4

While the present machine has only 1 generating unit for each harmonic, there is ample room for 2 or 3 or even more complete units around the periphery. With several such adjustable units, the phase as well as the magnitude values for several complex patterns, can be set in advance.

Electrical Circuit. The conductors from the stationary wave pattern plates are connected through switches to the grid side of a 10,000 ohm amplifier input resistance as shown in the schematic circuit diagram, figure 6. The other end of the input resistance is grounded through the potential controls. Since the frame is grounded, the steel disks and stationary plate supports keep the individual units thoroughly shielded from each other and from exter-

nal disturbances. Since the wave pattern plates are held about 0.3 inch from the rotor, the pattern plate may be considered as being in the same plane with its shield, inasmuch as the thickness of the insulating paper is only 0.01 inch. The wave pattern plate is, therefore, practically at ground potential since the drop across the input resistance is negligible, being on the order of 50 microvolts. The feeble capacitance currents are amplified through a specially designed amplifier which feeds an output of 2 watts into a 500 ohm impedance line with only 50 microvolts across the 10,000 ohm input resistance.

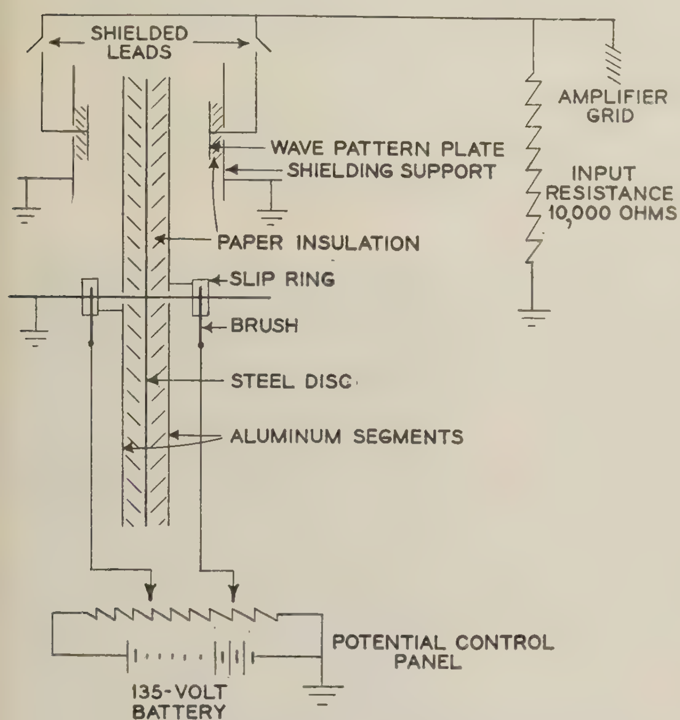


Fig. 6. Schematic circuit diagram of one rotor disk with its accompanying pair of harmonic generating units

Electrostatic Flux Distribution

A generalized form of the electrostatic field between the rotor and the wave pattern plate holder is shown in figure 7*a*. The segments are shown as if moved in a plane instead of in a circle; *A* represents a segment, *B* the steel disk, and *C* the pattern plate holder. Both *B* and *C* are at ground potential. The distance *MN* embraces the generating flux for one cycle. The pattern plate extends $^1/_2$ cycle. Since the pattern plate is practically in the same plane as the holder, *C*, the flux distribution on it may be considered the same as on the holder. Directly under the segment *MO* the flux is distributed evenly and is relatively dense. Near the edge of the segment the flux density quite sharply becomes diminished. Since the boundary of the holder is of greater extent than that of the pattern plate, the edge effect has little or no influence on the flux distribution in the vicinity of the pattern plate. Thus

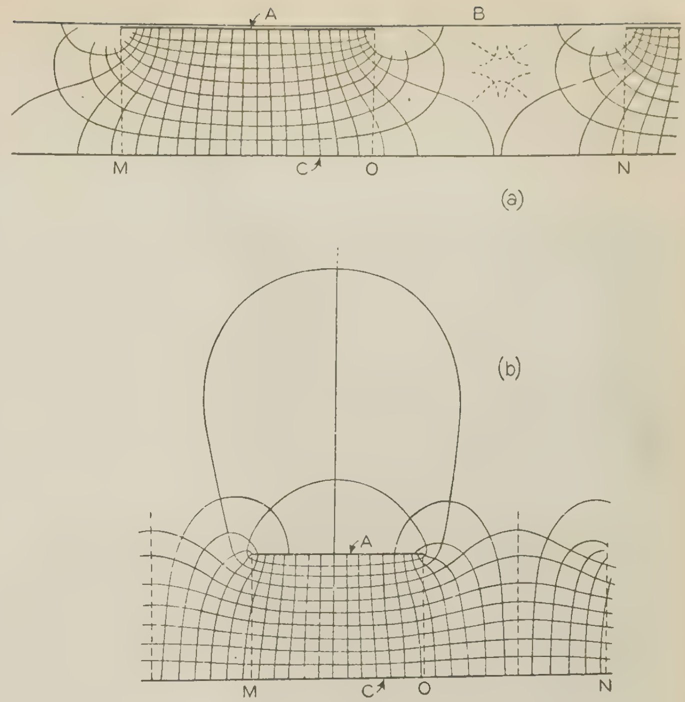


Fig. 7. Maps of the electrostatic field between stator and rotor (a) with shielding disk, and (b) without shielding disk

the distribution shown by figure 7*a* makes the coincident-area principle of design quite reliable. It is true that the lack of uniformity that does exist causes a certain amount of distortion in the resulting current wave; analyses, however, show that these distortions are small.

In order that all harmonic units would generate currents of the same magnitude, it was found necessary to place the wave pattern plates for the higher harmonics closer to the disks. As the segments become narrower a greater percentage of the flux from *A* goes to the steel disk *B*. To compensate for this the plate *C* must be moved closer to the rotor.

Figure 7*b* shows the field distribution without the use of the shielding plate *B*. Under these conditions there is no sudden change in flux density. Considerable flux comes around from behind segment *A* as well as from the edges and fills in between the segments. This arrangement would be highly unsatisfactory, but is shown here to point out the need of an adequate shielding system. Some improvement could be made by placing the plates closer together, but this would increase the distortion caused by vibration. Furthermore, the steel disk acts as a good shield between adjacent units.

Performance Characteristics

Performance tests included analyses of the individual harmonics for freedom from higher frequency components, a measurement of intensity variation over a series of waves, a check on linearity between the output and the setting on the potential control board, measurement of noise level, and a measurement of change in intensity caused by phase shifting.

Wave Form. Oscillograms of the individual harmonics were taken with a high quality galvanometer type oscillograph. These oscillograms then were enlarged and analyzed on a Henrici harmonic analyzer. Detailed results are given in table I. Analysis

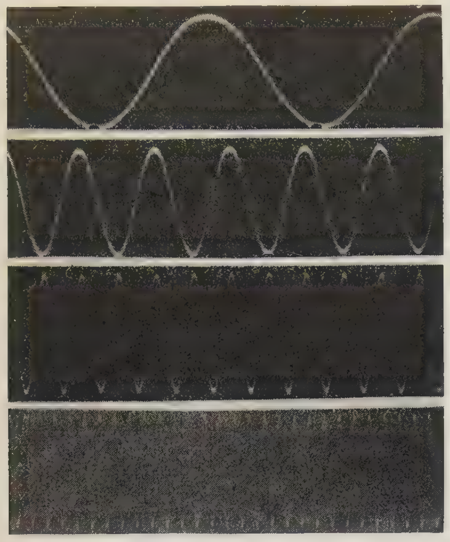


Fig. 8. Oscillograms of typical wave forms of generator output

Top to bottom: fundamental, and fourth, sixth, and fifteenth harmonics

was made for 5 components in each of the 8 lower harmonics and for 3 components in each of the 8 higher harmonics. In the lower harmonic group the stray component with the greatest magnitude was the second component of the third harmonic, which had an intensity 26 decibels below that of the fundamental component. The average intensity of the stray components of the first 8 harmonics was 37 decibels below the fundamental. In the upper harmonic group the worst was 22 decibels below the fundamental component, while the average was 30. The presence of this small percentage of stray components was caused largely by the summation of mechanical errors in plate tracing and cutting, faulty alignment of stationary plates relative to the rotors, and some departure from the flux distribution assumed in designing the wave pattern plates. Ali of the waves were viewed on a cathode ray oscillograph which showed them to be smooth and well defined. Some typical oscillograms are shown in figure 8. Combinations of 2 waves in different phase relationships are shown in figure 9.

Table I—Results of Wave Shape Analysis of Generator Output

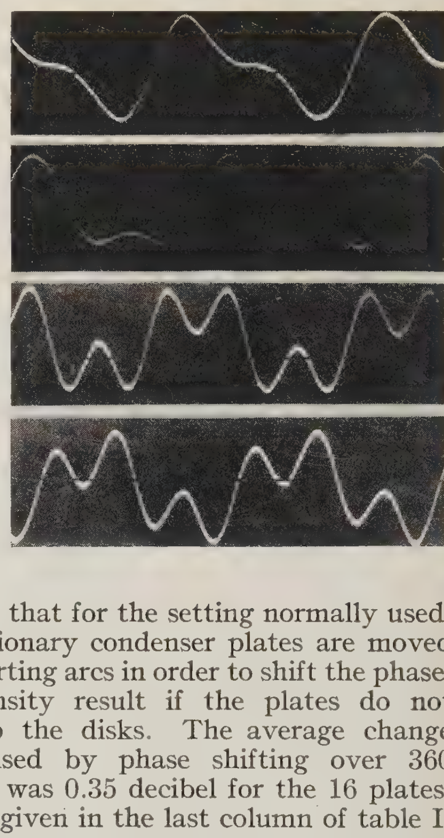
Generated Harmonic	Frequency, Cycles per Second	Average Intensity of Stray Components, Decibels Below Fundamental	Maximum Intensity Variation in a Series of Analyses, Decibels	Maximum Intensity Variation During 360° Phase Shift, Decibels
1	178	42	0.10	0.22
2	356	42	0.10	0.32
3	534	37	0.12	0.32
4	712	33	0.21	0.36
5	890	38	0.21	0.30
6	1,068	32	0.30	0.34
7	1,246	40	0.34	0.40
8	1,424	32	0.36	0.46
9	1,602	33	0.30	0.38
10	1,780	30	0.21	0.28
11	1,958	35	0.28	0.30
12	2,136	31	0.44	0.41
13	2,314	26	0.48	0.30
14	2,492	27	0.50	0.48
15	2,670	23	0.44	0.22
16	2,848	32	0.48	0.40

Intensity Variations. The greatest variation in intensity over a series of waves of a given harmonic was 0.50 decibel. The average maximum variation among the 16 harmonics was 0.30 decibel. Individual variations are shown in table I. These variations were caused for the most part by a slight misalignment of the rotating disks, which defect was most pronounced in the higher harmonic units where the stationary plates were closer to the rotating disks.

The output was linear to within one per cent of the slider settings on the potential control panel. The noise level was 40 decibels below the output level for the lowest possible potential setting, which is about

Fig. 9. Oscillograms showing combinations of harmonics in different phase relationships

Top to bottom: harmonics 1 and 2; same with 90 degree phase shift; harmonics 1 and 3; same with 60 degree phase shift



70 decibels below that for the setting normally used.

When the stationary condenser plates are moved along their supporting arcs in order to shift the phase, changes in intensity result if the plates do not move parallel to the disks. The average change in intensity caused by phase shifting over 360 electrical degrees was 0.35 decibel for the 16 plates. These values are given in the last column of table I.

Applications

The machine just described should have a wide range of application. While its use may be limited to frequencies of the audible range, 16 harmonics is by no means the limiting number. Given the analyzed results of any periodic wave form with harmonic constitution within the limits of the generator and that wave readily may be synthesized. By special plate designs and compact arrangements of rotors, different types of musical instruments might well evolve. A simplified arrangement could be used for demonstration purposes in classes studying electrical wave patterns. Known complex tones can be sent through communication channels or amplifiers to study phase and other distortions.

Additional applications readily will suggest themselves to workers in the audio frequency division of the communication field.

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Effect of Ultraviolet on Breakdown Voltage

The effect of ultraviolet light upon the breakdown voltage of sphere gaps subjected to impulse voltages is considered in this paper. It is shown that, especially for the smaller gaps and corresponding lower voltages, more accurate voltage measurements result when ultraviolet light is used. Photoelectric emission from the surface of the spheres is believed to be the cause of the improved accuracy. Without ultraviolet light, variations in the number of free electrons affect the result.

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THERE is always a continual demand for better methods and means for measuring unknown values. Naturally, the measurement of high voltages is no exception, and the sphere gap has retained its position as the accepted method mainly because of its advantages over other methods which have been proposed. Among the sphere gap's disadvantages, is its time lag when measuring impulse voltages. It was observed before the tests described in this paper that the sphere gap seemed inaccurate and was erratic when used to measure steep front impulse voltages of the order of 10 kv using 6.25 centimeter spheres.

It was found that by illuminating the spheres with a carbon arc light the readings became less erratic and presumably more accurate, confirming the observations of others.[1,2] The arc light was later displaced by a quartz-tube mercury-vapor lamp. This type of illumination was found to be more convenient and fully as satisfactory. Since in ordinary daylight the sphere gap behaved as described above, the illumination from the ultraviolet portion of the mercury vapor lamp spectrum was assumed to be affecting the spark-over.

It is well known that ultraviolet radiation influences the breakdown voltage of spark gaps. The effects on 6.25 centimeter sphere gaps at close spacings have been studied quantitatively, and the data are presented in this paper to emphasize the importance of considering the matter of irradiation when sphere gaps are used for measuring impulse voltages. From these data, the conclusion may be drawn that the use of ultraviolet light is warranted, especially for the lower potentials and smaller gaps, by the increased accuracy of measurement which results.

The following data apply to the 6.25 centimeter spheres which were used throughout this entire test. A quartz-tube mercury-vapor lamp was used to illuminate the spheres and its power input, which was 35 watts, was kept constant to provide constant light output. The surge generator was of the conventional type and the George cathode ray oscillograph was used to record and measure the spark-over voltage.

METHOD OF TEST AND RESULTS

Curves of the breakdown spacing of 6.25 centimeter spheres versus relative light intensities are

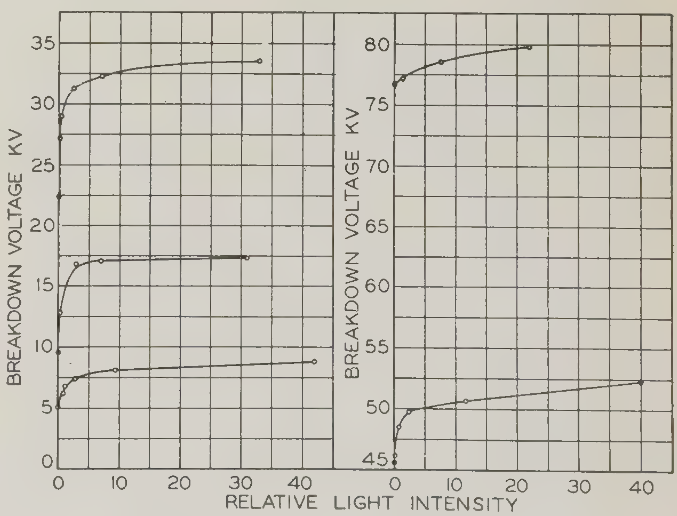

Fig. 1. The effect of different light intensities from a quartz-tube mercury-vapor lamp on the breakdown voltage of 6.25 centimeter bronze sphere gap

Each curve represents a different magnitude of impulse voltage wave

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. Great Lakes District meeting, West Lafayette, Ind., Oct. 24–25, 1935. Manuscript submitted May 8, 1935; released for publication July 31, 1935.

1. For all numbered references, see list at end of paper.

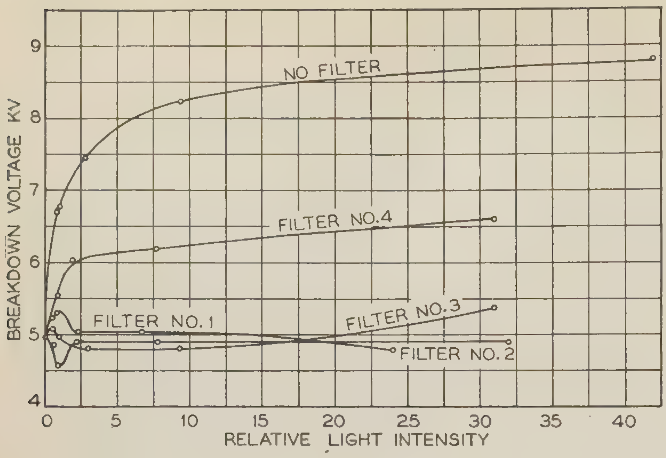

Fig. 2. The effect of different light frequencies from a quartz-tube mercury-vapor lamp on the sphere gap breakdown voltage

Filter No.	1	2	3	4	No. Filter
Cut-off frequencies of the filters, in Angstroms	3,340	2,920	2,540	2,380	2,250

presented in figure 1; the curves show the increase in length of gap required with increase in amount of irradiation of the spheres in order to just give breakdown of the gap on a definite impulse wave 50 per cent of the time. For each curve the shape of the voltage wave was kept constant and was an overshooting wave which for most of the curves, reached its peak in $^1/_2$ to 1 microsecond. Slight changes in wave form, however, prevent different curves of figure 1 from being exactly comparable. The intensity of radiation was varied by varying the distance of the lamp from the spheres. The lamp was permitted to illuminate both spheres with equal intensity and the line of radiation was perpendicular to the axis of the spheres. The axis of the spheres was horizontal and one sphere was grounded. The impulses were of such polarity that the ungrounded sphere was negative.

Figure 2 presents the curves of breakdown spacing versus relative intensity with different portions of the light radiation used to illuminate the spheres. In their numbered order, various light filters were used to transmit an increasing amount of ultraviolet light. The cut-off frequencies of these filters are shown in the caption of figure 2. These tests were conducted to obtain a fair idea of what wave lengths of light, within the range of the quartz-tube mercury-vapor lamp, had an appreciable effect on spark-over.

Other tests were made to determine whether ultraviolet light would affect spark-over using spheres of different metals. The metals used were chromium, copper, nickel, silver, and bronze. Each of the metals with the exception of bronze was plated on bronze spheres. It was found from the data taken, that ultraviolet light has practically the same effect on spark-over for all the metals used. Therefore, in all subsequent tests bronze spheres were used.

The erratic readings of the sphere gap without ultraviolet light seemed to indicate that breakdown was not occurring on the same part of the wave at all times. When ultraviolet light was illuminating the spheres, the readings became consistent and the spacings considerably larger for the same applied potential. It is true that the above tests were made under conditions which accentuate the time lag of the gap and the effect of the ultraviolet light in reducing this time lag. It was decided to determine on what part of the wave spark-over was occurring and if the sphere gap might possibly indicate more than the actual voltage. Curves of figures 1 and 2 indicate that the spacing at greater intensities is asymptotic to a constant value which it may be assumed represents the actual crest voltage of the impulse unaffected by time lag. To test this assumption it was decided to determine on what part of the wave spark-over occurs with and without irradiation.

Under the assumption that the then accepted calibration of the sphere gap could be relied upon for flat-topped, long-tailed waves, the oscillograph deflection was carefully calibrated and the actual crest voltage of the wave shown in figure 3 was determined by measurement from the oscillogram.

Tests With Reduced Spacings

The procedure in this test was to measure the voltage by the illuminated sphere gap, and then slightly reduce the spacing to obtain spark-over every time. Oscillograms taken of the breakdowns under these conditions are presented in figure 4. The spacing of the illuminated gap was then further reduced to provide breakdown on the front of the wave. Oscillograms of the breakdown on the front of the wave are shown in figure 5. Next, the voltage was measured by the sphere gap without using ultraviolet light. In order to take oscillograms of spark-over without light, it was necessary to reduce the spacing by

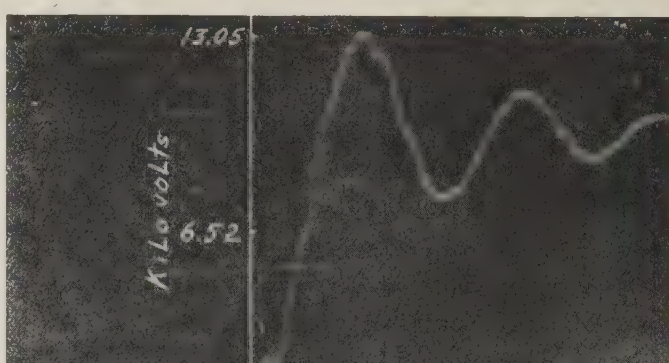

Fig. 3. Oscillogram of wave shape used in tests 1, 2, and 3

Test number	1	2	3
Crest voltage measured by oscillograph calibration, kv	13.05	11.28	11.28
Crest voltage measured by illuminated sphere gap*, kv	11.83	10.68	10.72
Crest voltage measured by non-illuminated sphere gap**, kv	6.79	7.54	6.79

* Gap spacing for test 1, 0.134 inches to give spark-over 50 per cent of the time.
** Gap spacing for test 1, 0.079 inches. Readings erratic and inconsistent for non-illuminated gap.

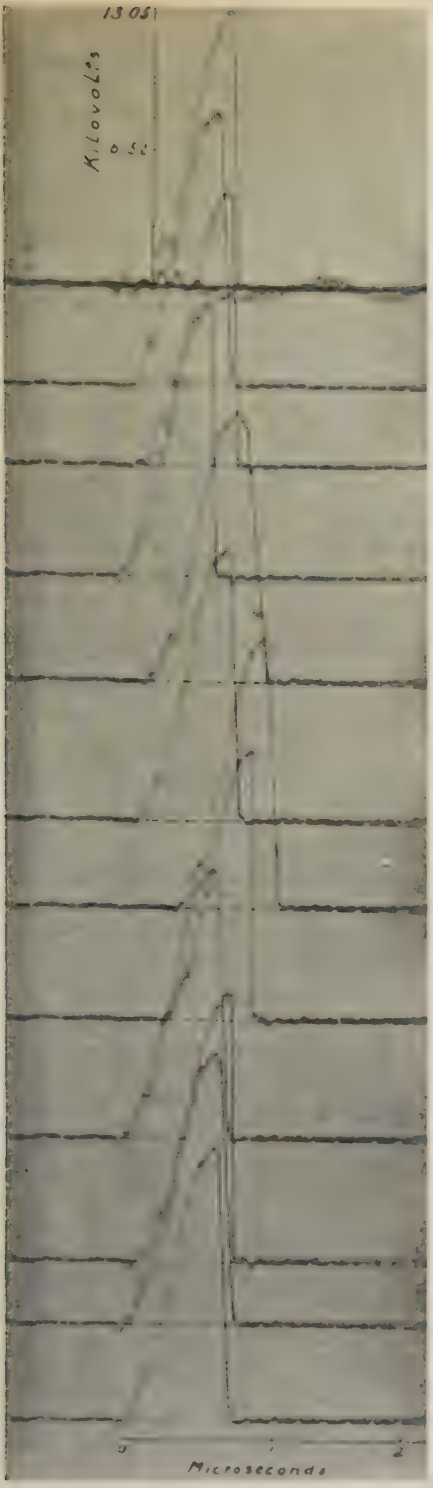

Fig. 4. Spark-over with ultraviolet light, showing test 1, only

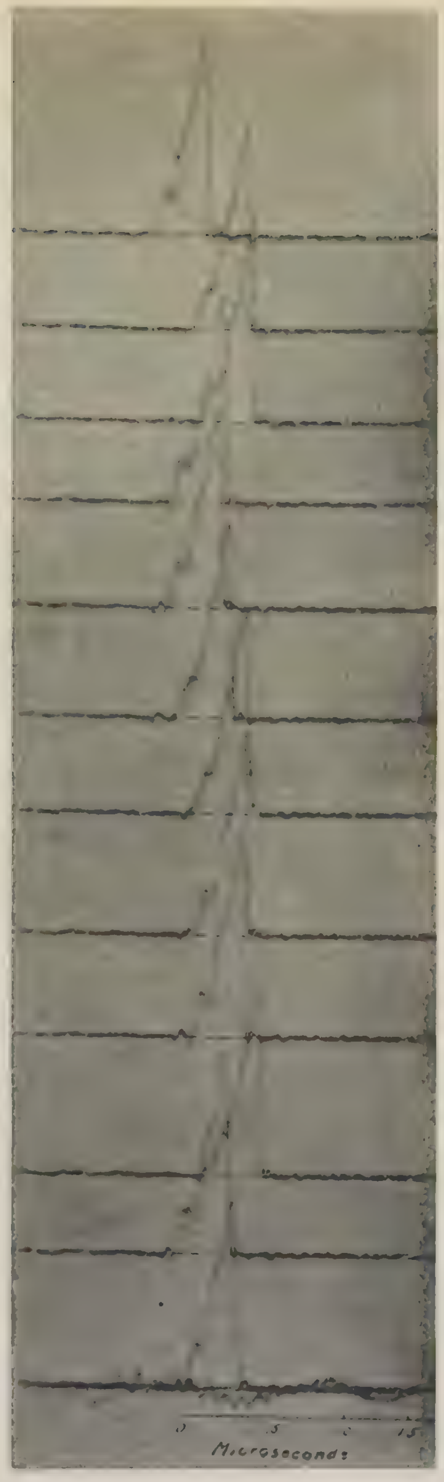

Fig. 5. Spark-over on front of the wave with ultraviolet light, showing test 1, only

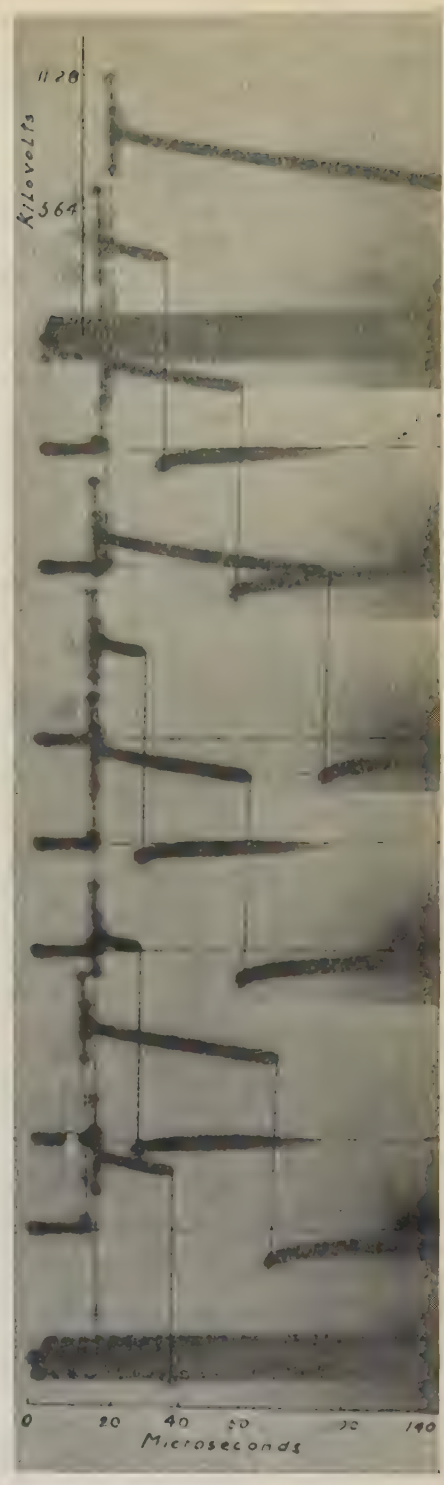

Fig. 6. Spark-over without ultraviolet light, showing test 2, only

Figs. 4, 5, and 6. Typical oscillograms showing spark-over of 6.25 centimeter spheres

	Fig. 4			Fig. 5			Fig. 6		
Test Number	1	2	3	1	2	3	1	2	3
Actual crest voltage of full wave by oscillograph calibration, kv	13.05	11.28	11.28				13.05	11.28	11.28
Above oscillograms taken with gap set for 0.133 inches,* kv	11.64	10.42	10.52						
Above oscillograms taken with gap set for 0.081 inches, kv				7.78	7.30	7.21			
Above oscillograms taken with gap set for 0.055 inches**, kv							5.25	5.62	5.11
Average value of voltage at break-down as measured from above oscillograms, kv	12.75	11.13	11.13	9.90	9.13	8.89			

* Gap setting slightly reduced to provide 100 per cent spark-over. Compare with voltage measurement setting (figure 3) for 50 per cent spark-over.

** It was necessary to reduce the spacing to this value before the gap would spark-over every time with even fair consistency.

about 35 per cent to make certain that spark-over would occur nearly every time. These oscillograms are presented in figure 6.

The above oscillographic tests were repeated 2 times in order to check results. For each of the 3 tests the results are given in the captions of figures

3, 4, 5, and 6. In each of these tests for each condition, 12 oscillograms were taken. For tests 1 and 2, the mercury vapor lamp was 7.5 inches from the center of the spheres, which is approximately 30 on the abscissa of figure 1. The last test was taken with the lamp 4 inches from the center of the spheres, which is a relative light intensity of approximately 100.

Figures 3, 4, 5, and 6 show convincingly the large time lag of small sphere gaps at small spacings for this type of wave and the effect of ultraviolet light in reducing this time lag.

In the tests using the calibrated oscillograph, the measurement of the crest voltage without light gave values of 52 per cent, 66 per cent, and 60 per cent of the actual crest voltage for tests 1, 2, and 3, respectively. The illuminated sphere gap gave values of 91 per cent, 95 per cent and 95 per cent of the actual crest voltage for tests 1, 2, and 3, respectively. Test 3, which was performed with the lamp 4 inches from the axis of the spheres, showed only slightly better accuracy.

From the above described tests it appears evident that the use of ultraviolet light has a decidedly beneficial effect in increasing the accuracy of measurement of the lower range of impulse voltages with small sphere gaps. For the illuminated gap, the oscillograms show that spark-over occurred very near the peak of each wave, while the oscillograms of spark-over of the nonilluminated sphere gap definitely show a decided time lag and therefore varying breakdown voltages. The type of wave used (see figure 3) accentuates the effect of the ultraviolet light since the voltage rises to crest rapidly and remains there only a short length of time. It had seemed desirable to determine the effect of ultraviolet light on this type of wave which occurs in measuring the impulse breakdown voltage of arrester gaps and flashovers of insulation or bushings which break down on the front of the wave.

Further tests were conducted to determine the desirability of using ultraviolet light when measuring the impulse voltages of proposed A.I.E.E. standard test waves. This was done by means of the calibrated oscillograph for the $1^1/_2 \times 40$, 1×10, 1×5, and $^1/_2 \times 5$ waves. Table I presents the data obtained from these tests and shows the accuracy of measurement in per cent of actual crest voltages. Three crest values of impulse voltages were used, ranging from approximately 10 kv to 80 kv. The lamp in these tests was 7.5 inches from the center of the spheres.

Table I—Accuracy of Voltage Measurement With and Without Ultraviolet Light

		Crest Voltage Measured by 6.25 Cm Sphere Gap			
		With Light		Without Light	
Wave	Actual Crest Voltage Kv	Kv	Per Cent	Kv	Per Cent
$1^1/_2 \times 40$	78.4	78.5	100	78.4	100
$1^1/_2 \times 40$	38.8	38.4	99	38.4	99
$1^1/_2 \times 40$	9.73	9.64	99	8.95	92
1×10	76.9	76.9	100	76.9	100
1×10	39.1	38.2	98	36.5	93
1×10	9.28	9.19	99	6.86	74
1×5	66.7	66.2	99	66.2	99
1×5	34.8	33.4	96	33.3	95
1×5	8.37	7.57	91	4.33	52
$^1/_2 \times 5$	72.3	72.9	101	72.8	101
$^1/_2 \times 5$	37.7	37.0	98	36.2	96
$^1/_2 \times 5$	9.12	9.11	100	6.01	66

Summary

1. From the data of table I the conclusion may be readily drawn that the use of ultraviolet light is quite desirable for sphere gap measurement of low impulse voltages even for the $1^1/_2 \times 40$ wave, and the increase in accuracy of measurement due to the light is more pronounced with lower potentials and consequently smaller gaps.

2. The effect of ultraviolet light in reducing the time lag of sphere gaps is believed to be entirely due to photoelectric emission from the surface of the spheres. If any ionization of the air is taking place, the ionization would only be a very short distance from the quartz tube since it is probable that the ions would be readily deionized by the air around the tube. The results shown in figure 2 and the definition of surface photoelectric effect,[6] are evidence of the fact that the effect of ultraviolet light radiation on sphere gap breakdown is due to photoelectric emission from the surface of the spheres. In order to obtain maximum emission from the surface of the spheres, it is necessary that the surfaces be as clean and free as possible from any oil film left from cleaning the spheres. The electrons thus produced are available for acceleration and ionization when the proper gradient is reached.

3. Without ultraviolet light on the small gaps the relatively large and variable time lags seem to be the result of a variable and at times, insufficient number of free electrons to provide rapid ionization when the necessary gradient is reached. An insufficient supply of free electrons in the strongest part of the field may be the result of a naturally low density at the start of the rise in voltage; or, due to the short gap length, a large number of the available electrons may be drawn to the positive sphere before the ionizing gradient is reached. The fact that ultraviolet light provides an abundant and continually replenished supply of free electrons appears to reduce the effect of both of the above sources of time lag. The fact that the time lag of the sphere gap decreased with increased spacing is in line with the above theories. For greater spacing between the spheres the electrons would have to travel a greater distance to reach the positive sphere, thus, with the same rate of rise, the voltage would reach an ionizing gradient in time to make use of these electrons. Also, with a greater volume of air between the spheres the normal electron density would be more apt to prevail in the strongest part of the field.

4. Finally, it is believed that ultraviolet radiation on the small sphere gaps increases the accuracy of measurement by an amount sufficient to warrant its use for the measurement of impulse voltages.

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Magnetic Fields in Machinery Windings

In presenting the results of his studies of the magnetic field in and near the conductors of electrical machinery, the author seeks to fill the gap existing between the present accurate but difficult methods and the easier but less accurate methods of drawing and calculating these fields.

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THERE IS a wide gap in the methods of drawing and calculating the magnetic fields in the copper windings of machinery. Those that are most accurate are hard to understand and to use. The easier methods of calculation are less accurate, and the easier graphical methods are harder to analyze. This paper endeavors to fill this gap by showing how the method of superposition yields a rapid, accurate treatment, which is easily analyzed for the effect of the various modifying factors. It leads to methods of drawing the fields, and estimating their flux interlinkage. The investigation shows that:

1. Most of the fields in and near the copper conductors of machinery may be resolved into 3 simple components that are easy to draw and to use for computations.

2. Superposition of these components leads logically and simply to the resultant.

3. In certain cases this resultant field is a conic section; in others it contains a term of the type $\epsilon^{-kx} \cos ky$.

4. The fields laid out by this method are easily blended near pole tips and slot openings with the field more remote from the copper, found by other graphical methods.

The fields inside and outside of a current-carrying conductor are radically different in character, as indicated in figure 1. The heavy circle represents the surface of the wire, and the lighter circles lines of force spaced so that each tube of force contains the same flux. The law of flux density is shown at the right, and the discontinuity at the surface of the wire is apparent. The field outside the wire has a potential function and is termed "lamellar." Inside the wire there is no potential function, and the field is termed "vortical." In this region the "curl" of the field is said to be proportional to the current density. The center of the wire O is in this case the point at which the lines of force converge. Such a point is termed the "core" or "heart" of the field. The flux function at the point P is said to be -10, because there are 10 lines of force between it and the heart of the field, and minus because the flux is counterclockwise.

The radial lines in figure 1 designate equipotential surfaces outside the wire, but inside the wire there is no magnetic potential, so that in this region the radial lines are termed "level surfaces" or "lines of no work." The heavy radial line OA is an arbitrarily selected datum surface from which to reckon potential. It may be termed a "magnetic shell," or "cap surface." The magnetic potential on the right-hand side of this surface is the full ampere turns of the coil; on the left-hand side of this surface the potential is zero. The potential at any point such as P is proportional to the crosshatched area.

All resultant magnetic fields are "solenoidal"; that is, in any region there are as many tubes of induction entering as leaving its boundary surface. Stated in other words, the "divergence" is said to be zero. In insulation there can be no current except displacement current, and in a steady state the "curl" of the field in such a region must be zero. It is to be noted, however, that these restrictions apply only to the resultant field.

Component Solutions

The fields described in this paper can be built up out of 3 simple components by the method of superposition. These components are, respectively, the

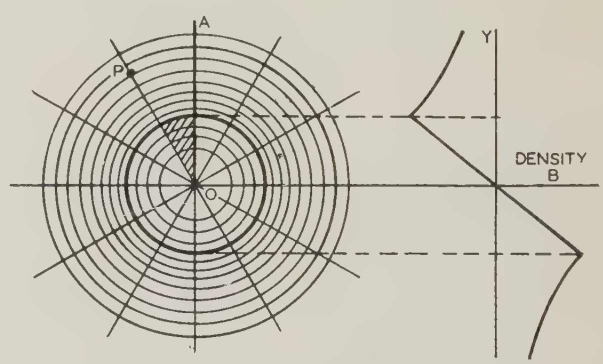

Fig. 1. Diagram illustrating lamellar and vortical fields

field inside the slot of a dynamo, the field between transformer coils, and the field which would be set up by an imaginary surface magnetized sinusoidally, with the same polarity on both sides. The restrictions as to divergence and curl do not apply to component fields, which are merely aspects of the total phenomenon. In this case all that is necessary is that the divergences of the component fields neutralize each other. It is also necessary in insulation that the values of curl for the component fields shall neutralize.

Components of the magnetic field are further classified as "main" and "compensating" components. By main component of a field is meant that simple field

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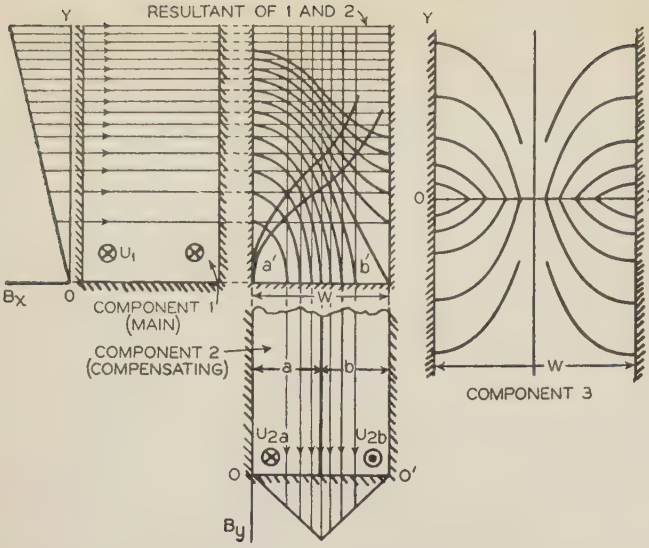


Fig. 2. Diagram showing superposition of elementary fields

which most closely approximates the actual field, and which leads to simple approximate formulas for the inductance and leakage flux. By compensating component is meant the remaining minor, and simple, component of the field which compensates the main field for any error in curl or divergence. For example, if the main field shows divergence, the compensating field should neutralize this divergence. Or again, if the main field shows curl in insulation, the compensating field neutralizes this curl.

These 3 component fields are further described in figure 2. At the left is shown a slot carrying a current of density U_1. The flux lines are horizontal, the density increases as y and the flux function at any point is

$$B_1 = 3.2\ U_1 y$$
$$\phi_1 = 1.6\ U_1 y^2 \qquad (1)$$

in inch units. If the lines of force divide the flux into tubes of $\Delta\phi$ lines each, the ordinate of the nth line is

$$Y_n = \sqrt{\frac{n\Delta\phi}{3.2\ U_1}} \qquad (2)$$

The condition for every tube to contain the same number of lines is essential if the fields are to be superimposed.

At the bottom of figure 2 are shown 2 coils carrying equal and opposite currents, much as in a transformer. The field is vertical, and the density is triangular and maximum between the coils. If U_2a and U_2b designate the current density at the left and the right, the flux functions are

$$B_{2a} = 3.2 U_{2a} x;\quad \phi_{2a} = 1.6\ U_{2a} x^2 \qquad (3)$$

$$B_{2b} = 3.2\ U_{2b} x';\quad \phi_{2b} = \phi_t - 1.6 U_{2b} x'^2 \qquad (4)$$

Where ϕ_t is the total flux represented by the area of the triangle of density B_y; x is the abscissa drawn from the center O; x' is the abscissa drawn from the center O'.

The lines are drawn so as to contain the same amount of flux ϕ as before.

1. For all numbered references see list at end of paper.

At the right of figure 2 is shown the third component field. This field is represented by the equation

$$\phi + jV = A\epsilon^{(\pm y + jx)\left(\frac{\pi}{W}\right)} \qquad (5)$$

where V is the potential and y is, respectively, less and greater than zero. Upon expanding this exponential there is obtained

$$\phi + jV = A\epsilon^{\pm\left(\frac{\pi y}{W}\right)}\left(\mathrm{Cos}\frac{\pi y}{W} + j\sin\frac{\pi x}{W}\right) \qquad (6)$$

which is periodic in x. Thus the field need be drawn only between $x = O$ and $x = W$. On these 2 lines $V = 0$, and hence they may be iron surfaces, as represented in the figure. It is to be noted that there is a divergence of 20 tubes of force on this line $y = 0$.

Method of Superposition

The method of finding 2-dimensional vortical fields used by Hague,[1] Rogowski (see Stevenson[2]), and Park and Stevenson,[3] is by integration of the field created by each filament of current. Their methods are of great generality but of considerable difficulty.

The method of superposition is well illustrated in figure 2. The horizontal lines from the left-hand figure have been carried over to the right, and the lines from the lower figure are carried upward so that they intersect. A new system of lines has been drawn through the intersections of the 2 components in such a manner that the flux function ϕ on each of the lines is a constant, and the sum of the flux functions of the 2 component fields. The current densities also combined algebraically. Thus we have the equations 7 and 8 in regions a' and b', respectively.

$$U_a = U_1 + U_{2a};\quad \phi_a = \phi_1 + \phi_{2a} \qquad (7)$$

$$U_b = U_1 - U_{2b};\quad \phi_b = \phi_1 + \phi_{2b} \qquad (8)$$

The term superposition is peculiarly appropriate when, as in some of the more complicated cases, the figures are laid out by superposed sheets of tracing cloth. While it is believed that most books do not give enough attention to superposition, superposition methods have been used, but chiefly with lamellar and solenoidal fields. The author knows of one

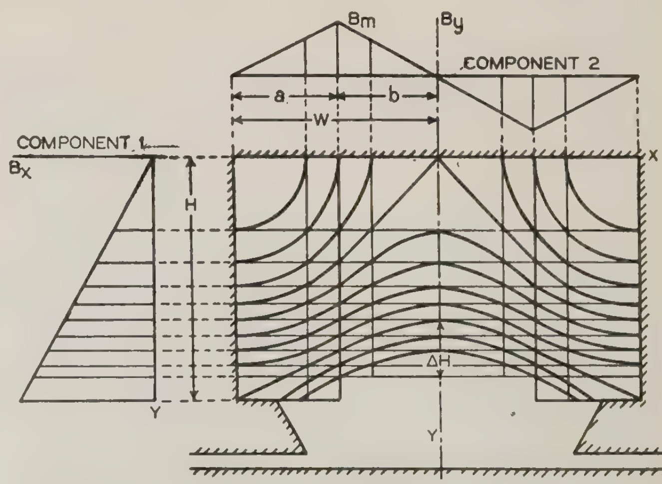


Fig. 3. Interpolar field in a shunt generator

example of superposition of a vortical with a lamellar field.[4] It is believed that one of the elements of novelty in this paper lies in the combination of vortical fields and the combination of 2 divergent fields.

Each of the 2 component fields has a density varying in a linear manner. Now, since energy storage varies as the density squared, and the volume of the 2 fields is the same, the ratio of the energy in the compensating field to that in the main field is as the square of the ratio of maximum densities, or if H is the depth of the slot,

$$\text{Energy ratio} = \left(\frac{U_{2a}}{U_1}\right)^2 \left(\frac{a}{H}\right)^2 \tag{8a}$$

Figure 2 was drawn for the following particular data:

Dimensions, $a = b = 1$ inch.
Current densities, $U_1 = 500$, $U_{2a} = U_{2b} = 1000$, $U_a = 1500, U_b = -500$.
Flux functions, $\phi_1 = 800\, y^2$, $\phi_{2a} = 1600\, x^2$, $\phi_{2b} = 3200 - 1600(x')^2$, $\phi = 400$ lines. The densities are in inch units.

Resolution of a Field Into Its Components

In the previous discussion of figure 2 we assumed that the component current densities were given. We will now investigate the conditions which must be satisfied by the component densities when the resultant densities are given. One component field must be similar to that in a slot, that is, the current is assumed to be uniformly spread out. The remainder is the compensating field. Thus,

$$U_1 W = U_1 = (a + b) = U_a a + U_b b \tag{9}$$

$$U_{2a} a = U_{2b} b = (U_a - U_b)\frac{ab}{W} \tag{10}$$

There is also a noteworthy difference in physical interpretation between the methods of the last 2 articles. When we have actual components vortical in character there must of necessity be copper wherever there is current. In resolving the field in insulation into components, current densities will be indicated equal and opposite and neutralizing. Thus the compensating field may be said to compensate for the error made by assuming the main field only to exist, with its curl in the insulation. The principal of superposition rests of the linear character of the differential equations of the field.

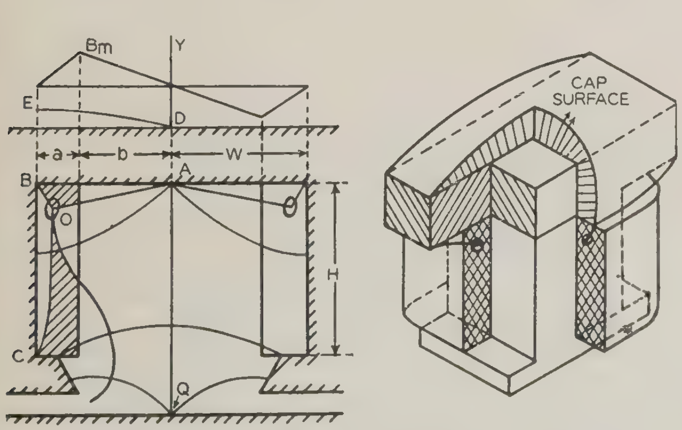


Fig. 4. Visualization of cap surface for a dynamo

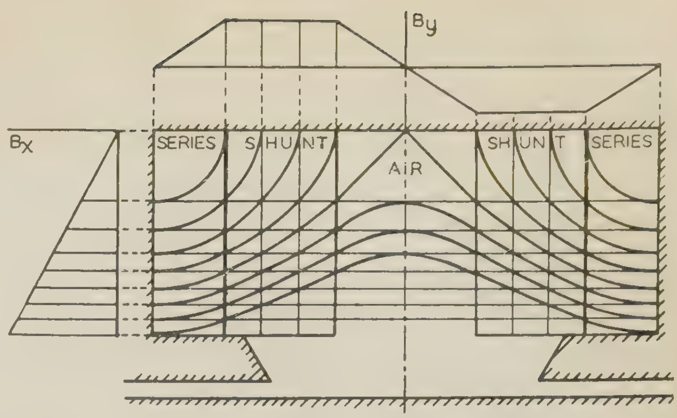


Fig. 5. Interpolar field in a compound generator

Shape of the Lines of Force and Level Surfaces

Again referring to figure 2 we note that the lines of force are ellipses and hyperbolas. This is easily established in the following manner: substitute equations 1 and 3 into 7 to obtain the new equation 11, and equations 1 and 4 into 8 to obtain the new equation 12, thus

$$\phi_a = 1.6\, U_1 y^2 + 1.6\, U_{2a} x^2 \tag{11}$$

$$\phi_b = \phi_t + 1.6\, U_1 y^2 - 1.6\, U_{2b}(x')^2 \tag{12}$$

which are the equations of ellipses and hyperbolas. The ratios of axes of the conics $\frac{B}{A} = \sqrt{k}$, (or y intercept to x intercept), are

$$\left(\frac{B}{A}\right)_a = \sqrt{\frac{U_{2a}}{U_1}};\ \left(\frac{B}{A}\right)_b = \sqrt{\frac{U_{2b}}{U_1}} \tag{13}$$

In certain cases the ellipses are circles, and the hyperbolas are rectangular, the latter being true in insulation, for example.

The level surfaces or lines of no work are those systems of lines which are orthogonal to the flux lines. If we denote the ratio $\frac{B}{A} = \sqrt{k}$, the level surfaces are parabolas of the kth degree, defined by the equation

$$x = Cy^k \tag{14}$$

One or 2 such lines are also shown in figure 2. We should also note that while the boundary of the field is shown as iron, any side may be a line of symmetry dividing the field as shown from its "image" field.

By way of summary for the preceding 3 sections, we may say that the fields are easily laid out on the drawing board, and the 2 component fields afford a convenient starting point in solving for inductance and leakage flux.

Interpolar Field of a Shunt Generator

In a multipolar machine the interpolar space is a close approximation to a rectangle, and the field is a

close approximation to that just considered. In drawing such a field, we begin the construction near the yoke by the methods just outlined, and near the pole tips we would blend it into that obtained by present methods, as outlined by Moore and Lehman.[5] The neutral axis is a line of symmetry. The yoke and the 2 pole cores form surfaces of symmetry. The main component of the leakage field is that obtained by assuming that the field current is spread uniformly over the whole interpolar space. This component gives the usual formulas for pole core leakage, although most books underestimate the leakage from the pole ends.[6] The compensating field will give a new term to be considered.

In figure 3 are shown the 2 component and the resultant fields in a shunt generator when the shunt coils occupy 50 per cent of the interpolar space. The horizontal field is the main and the vertical field is the compensating component. The resultant field is circular in the shunt coils, and equilateral hyperbolas in the insulation. The area of the triangle of flux density on the yoke surface indicates the "yoke" leakage flux, a component which apparently has hitherto been neglected. Yet it should not be neglected, as the saturation of the magnetic circuit will cause a small error in leakage flux to make a larger error in ampere turns. Since the flux is distributed along the yoke we may imagine it as concentrated at a point half way between the pole edge and the neutral axis.[7] Moreover, the vertical component of the field determines the shape of the lines near the pole tip. Thus, referring to figure 3, note the dimensions, a, b, W, H, ΔH, the ampere turns of the coil M, the maximum yoke density B_m, the yoke leakage flux ϕ_y, the pole tip leakage flux caused by the compensating component of the field ϕ_p, and ΔP_p, its permeance.

$$B_m = 3.2\frac{M_b}{HW};\ \phi_y = 0.5\,B_m W = 1.6\,M\frac{b}{H} \tag{15}$$

$$B_p = 3.2\frac{M}{W};\ \Delta H = \frac{\phi_y}{B_p} = \frac{Wb}{2H} \tag{16}$$

$$\Delta P_p = 1.6\frac{H}{W} = 0.8\frac{b}{H} \tag{17}$$

It is believed that the effect of both the yoke leakage ϕ_y and the extra pole tip leakage ΔP_p is sufficient to warrant consideration for accurate results.

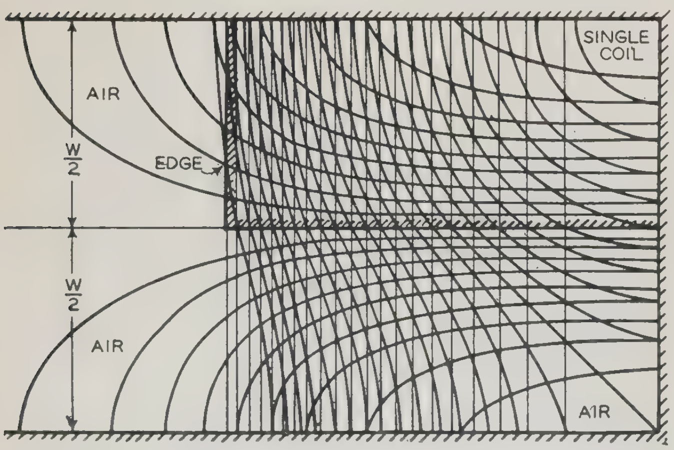


Fig. 6. Field in a shunt machine, showing edge effect

Surface of Zero Magnetic Potential in a Generator

The author has been unable to find any absolute value of magnetic potential assigned to the parts of the field of a dynamo. Since potential is a multivalued function, the magnetic circuit must be capped with a diaphragm which may serve as a datum from which to reckon magnetomotive force. In general this surface is arbitrary, but here considerations of symmetry almost require that the neutral axis be taken as one part of the surface of zero potential. In Figure 4 an attempt is made to visualize this cap surface. In this figure O is the heart of the field, the line DAQ is the neutral axis, and the line $OADE$ the trace of the cap surface. It is the line required in that it is a level line inside the coil, an equipotential outside the coil, and touches the neutral axis. On its inside surface and outside the coil the potential is the full amount of the field coils. On its outside surface the potential is zero. As it is believed this is the first attempt to depict this surface for a dynamo, the isometric projection is included in the figure showing the cap surface.

In figure 4 the effect of saturation in the core and yoke is shown by the core of the field being moved in from the corner where the iron core joins the yoke. The sectorial areas AOB and BOC represent the ampere turns lost respectively in the pole yoke and core.[4]

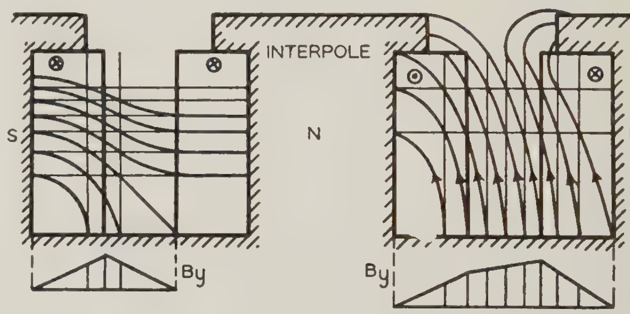


Fig. 7. Field at interpole

Interpolar Flux in a Compound Wound Machine

Figure 5 shows the flux lines in a compound wound generator, when the series coils are next the core, for that particular overload which makes the current density in the shunt coil the same as the average density in the interpolar regions. The figure shows the field resolved into its main and compensating components, one of which varies as y, and the other of which is trapezoidal. The diagram is of interest in that the lines of force in the shunt coil are parabolas.

The fields near the edge of the field coils of a shunt machine are distorted by the pole tips, the armature iron, and by a coil edge effect. It is believed that

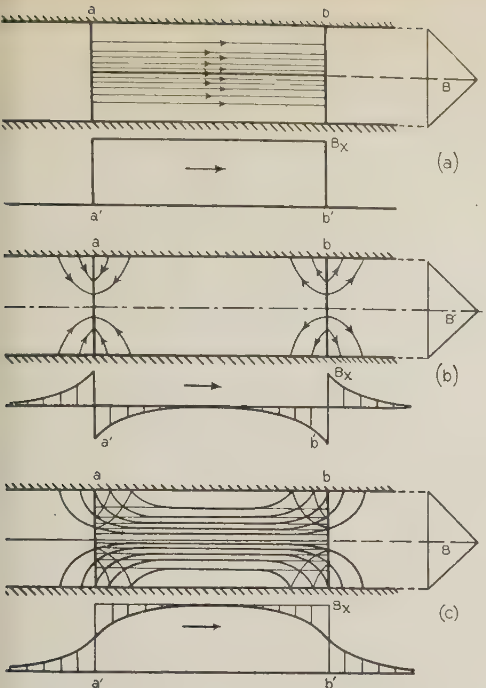


Fig. 8. Field in transformer coils

a. Main component
b. Compensating component
c. Total field

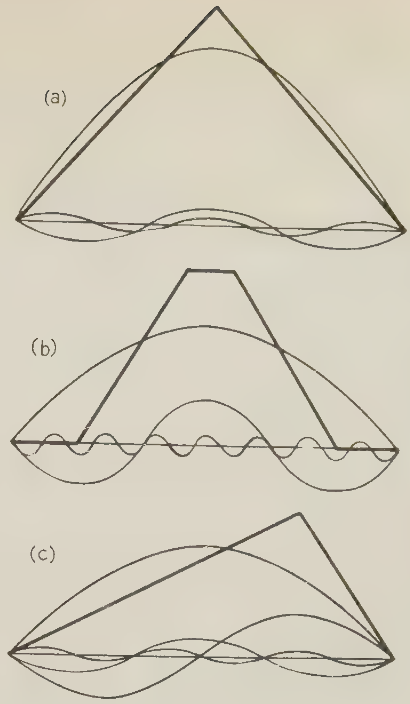


Fig. 9. Waves of flux density

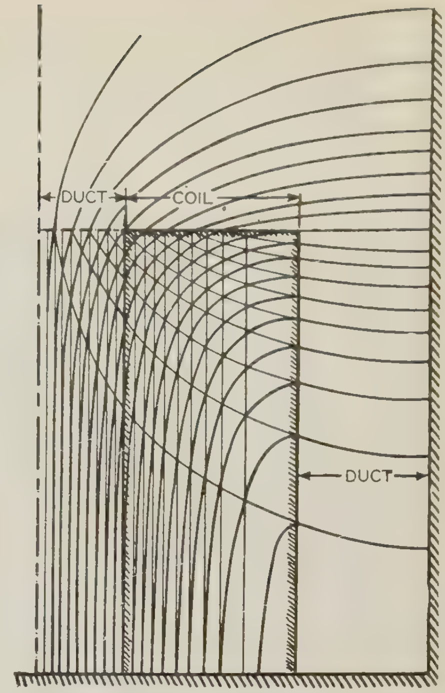


Fig. 10. Field in a transformer with ducts

the more usual graphical methods give the best guide in allowing for all these effects. Nevertheless figure 6 is included for theoretical interest. It represents the field between 2 short field coils but which have long pole cores. It is obtained by the superposition of a "slot" field and a field of a short transformer pair, as in figure 13.

Figure 7 shows the field in an interpolar machine for about half load, when the strength of the interpolar coils is about half that of the coils on the main poles. It is included to show how the method of superposition applies to this case also.

Main and Compensating Fields in Transformer Leakage

In figure 8 are shown the main, compensating and resultant leakage field in a transformer for the case when there are no oil ducts, but there are spaces between the coil ends and the yoke iron. One panel of the field only of a shell type transformer is shown.

Figure 8*a* shows the main component of the field. This field has a triangular density in y and a rectangular density in x. The lines of force come to a sudden end on the lines aa' and bb'. This component is that usually assumed in computing inductance, and meets the curl conditions exactly. It is, however, only a component, as it shows divergence along the lines aa' and bb' and must therefore be completed by another component which will neutralize the divergence on these lines.

Figure 8*b* shows the compensating component of the field. It not only neutralizes the divergence, but must meet the condition of curl = 0 at all points. It is to be noted that the longitudinal density caused by this field component operates to decrease the flux linkages.

Figure 8*c* shows the 2 component fields put together. It is to be noted first that 50 per cent of the flux comes out through the sides of the coil, decreasing the inductance. It is also to be noted that the curve of longitudinal density B_x is a smooth curve.

Building Up Compensating Fields

The iron surfaces in figure 8 are surfaces of symmetry, so that the field is periodic. It may be represented by a Fourier series of the type

$$\phi = \Sigma A_n e^{-(\pi n x/W)} \cos(\pi n y/W) \tag{18}$$

which gives the longitudinal density at the point x, y

$$B_x = \frac{d\phi}{dy} = -\Sigma A_n \frac{\pi n}{W} e^{-(\pi n x/W)} \sin(\pi n y/W) \tag{19}$$

On the line ($x = 0$) the exponential is unity. The problem in any particular case is therefore to choose the constant A_n so that the required wave of density is obtained. In particular, for a triangular wave, calling $B_m = 100$ per cent,

$$B_n = \frac{81}{n^2}\,;\, A_n = \frac{(WB_n 81)}{(\pi)(n)^3}$$

Figure 9 shows several such waves of flux density, representing (*a*) 2 equal coils in contact, (*b*) 2 equal coils with spaces between them, and (*c*) unequal sized coils in contact. In graphing a field such as shown in considerable tabular work must be done. The steps are essentially as follows: Values of $\pi y/w$ are taken every 10 degrees, as are a series of values of x/W. Values of ϕ are then calculated for the double series. The value of ϕ is then plotted against x, and values of x are taken off the curve for

uniform increments in ϕ. The compensating field is then easily drawn. In computing inductance the simplest procedure is to neglect all except the principal harmonics.

Special Transformer Fields

There are many possible special cases of fields with transformer coils. The following have been chosen because of novelty or because they afford a good illustration of the method of superposition. They are obtained by combining more elementary fields.

Figure 10 is an interesting and novel case. It represents the field between the coils of a transformer when there are oil ducts between the primary and secondary coils and between the coils and the neutral lines. The field is characterized in places by lines of reversed curvature.

In figure 11 is shown the effect of the iron yoke on the transformer leakage field. The yoke surface is treated as a mirror, and an "image" coil is assumed at the same distance h behind the yoke as the actual coil is in front. The real component is shown by solid and the imaginary component by dotted lines. The components are combined in the usual way. The effect is to increase the inductance.

Figure 12 shows the effect of 2 equal opposing pairs of coils edge to edge. It differs from figure 8 in that 100 per cent instead of 50 per cent of the flux comes out through the side. The inductance is considerably reduced, in fact the decrease of inductance is twice that in figure 8. In a similar manner the effect of short coils may be shown. Figure 13 shows the field of a transformer pair which is very short. It shows clearly the decrease in flux interlinkage which this causes. It is built up of components as shown in figure 8.

Estimation of Transformer Inductance

The decrease in inductance from the simple formulas usually given may be estimated by considering graphs of longitudinal density. For example, in figure 8*c* the rectangle is the linkage on the usual assumption, and the crosshatched area represents the loss in inductance.

Figure 14 shows similar graphs of longitudinal density, in comparison with the rectangle, for 2 cases. The first represents the iron yoke effect; the second represents the short coil effect. They are obtained by a simple analysis. In figure 14*a* the crosshatched area represents loss of inductance. The curve is an exponential with an initial value of $(0.5)\ (1-\epsilon^{-2\pi h/W})$, and an exponent of $-\pi x/W$. The area lost (due to one end) is the integral from 0 to D.

$$\frac{\Delta L}{L} = 100\,\frac{W}{2\pi D}\,(1-\epsilon^{-2\pi h/W})\int_0^D \epsilon^{-\pi x/W}\,d\pi x/W$$

$$= 100\,\frac{W}{2\pi D}\,(1-\epsilon^{-2\pi h/W})\,(1-\epsilon^{-\pi D/W}) \qquad (20)$$

This includes both the short coil and yoke iron effect. In this calculation all but the first term of the Fourier series were neglected. In certain more complicated cases they also would have to be considered. Figure 14*b* shows the short coil effect. The correction factor in equation 18 is given as a percentage of the inductance as calculated by the methods to be found in nearly every book. It is a modification and expansion of Rogowski's correction factor.

Main and Compensating Field in Slots

The main and compensating field in the case of armature slots is much like that in the interpolar

Fig. 11. Effect of iron yoke on transformer leakage field

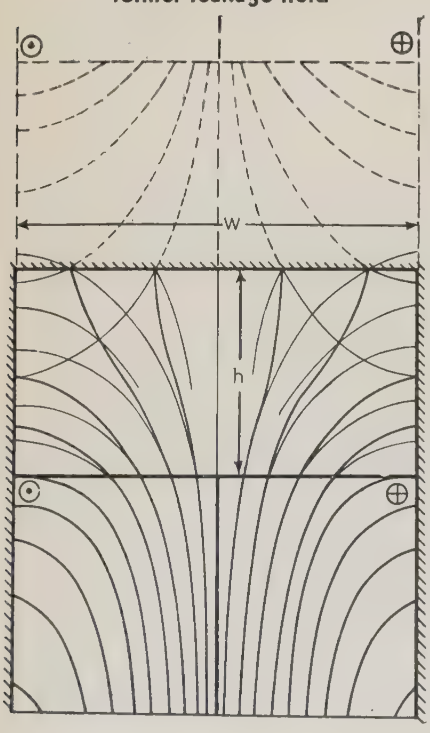


Fig. 12. Field with opposing transformer coils

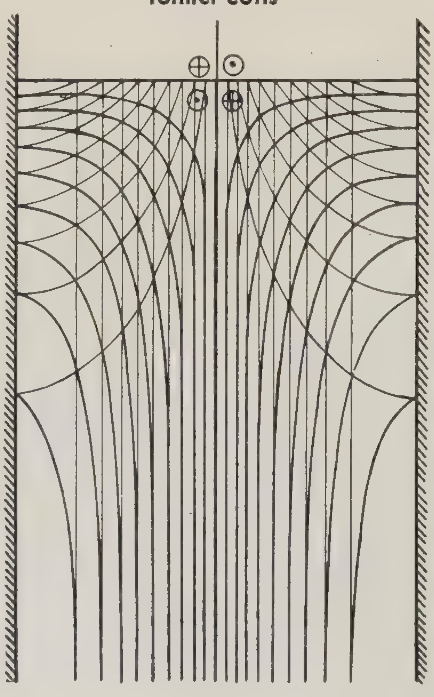
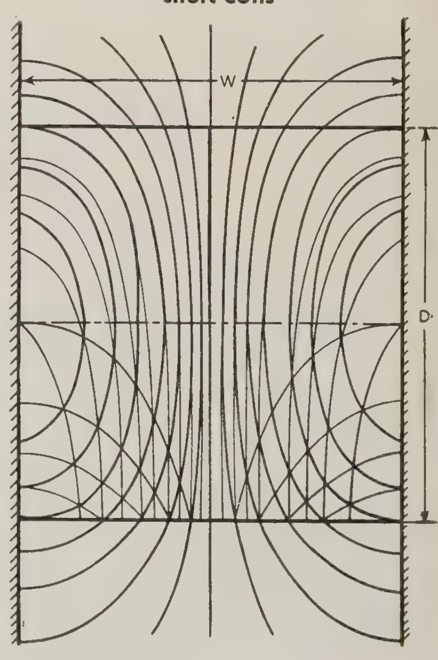


Fig. 13. Field of a transformer with short coils



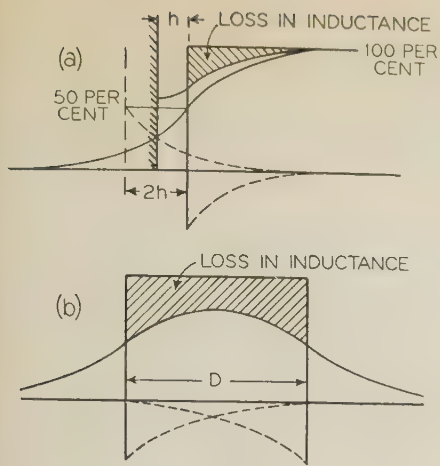


Fig. 14. Effect on transformer inductance of yoke iron (a) and of short coils (b)

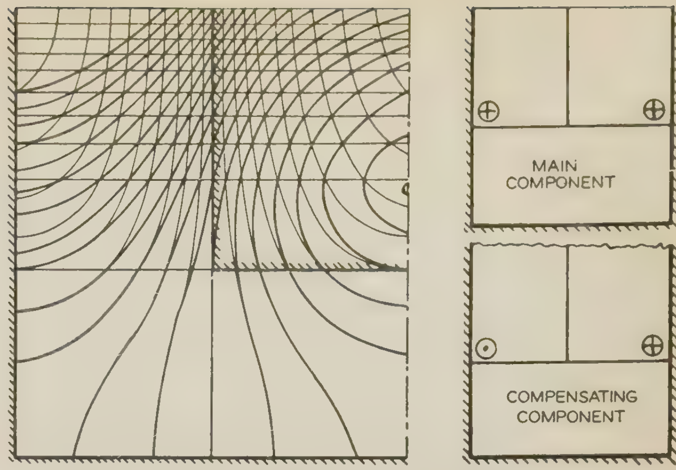


Fig. 16. Field in armature slot with full insulation

regions of a dynamo in its shape. The simplest example is shown in figure 15, in which there is insulation on the sides of the conductor, but not on the bottom. Although not a practical case it will introduce us to the subject. The horizontal component is that of the main field, and the vertical component of triangular density is the compensating field. This is chosen so as to neutralize the curl in the insulation. The usual formulas for inductance regard the main component of the field only.[8]

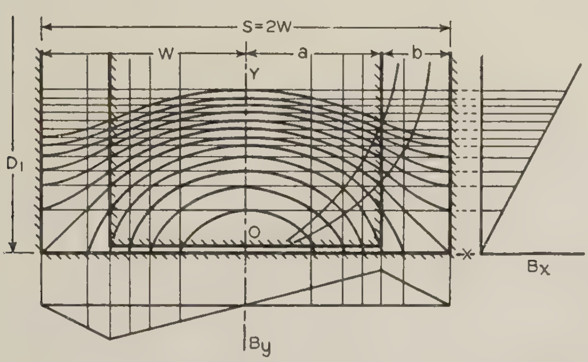


Fig. 15. Field in armature slot with side insulation only

The value of tooth tip and slot opening leakage appears to be somewhat too small in many of the formulas. The author considers his 1915 formula for slot opening leakage the closest, and finds that recent work confirms this.[6] Stevenson and Park have delineated the flux inside a slot but the writer does not consider the results susceptible to easy calculation of inductance. Novelty is claimed here only for method, and some special cases.

In figure 15 let us assume that we have an open slot of depth D_1 below the wedge and depth D_2 from surface to top conductor. The usual formula for inductance is, per inch of slot,

$$L' = 3.2(2n^2)\left[\frac{D_2}{W} + \frac{D_1}{3W}\right] \qquad (21)$$

It is not particularly easy to compute the interlinkages of the compensating field directly, so resource will be had to theorems in stored magnetic energy. We will use the following propositions:

1. For a given current inductance is proportional to stored energy.

2. In any elementary volume the energy stored is proportional to B^2, the square of the induction.

3. At any point $B^2 = B_x^2 + B_y^2$, so that the total energy may be found considering component fields separately.

4. Energy in a field in which the density varies as a straight line has $^1/_3$ the value it would have if the maximum density were to prevail throughout. (This is because the integral of x^2 is $x^3/3$.)

We have therefore the following proposition: The energy in the compensating field is to that in the main field as the square of the ratio of the maximum densities. If b is the thickness of insulation and $\Delta L/L$ the per cent error in the inductance,

$$\frac{\Delta L}{L} = 100\left(\frac{b}{D_1}\right)^2 \text{ per cent} \qquad (22)$$

It is to be noted that the error is not considerable except in heavily insulated and shallow slots. With insulation on the bottom of the slot the above figure would be decreased slightly.

Special Armature Leakage Fields

Figure 16 shows a slot in which the conductor is half of the width of the slot and insulated equally on the bottom and the sides. The main component of the field is the usual slot flux; the compensating field is similar to figure 11; in fact, it is identical. The resultant field is the same as given in the paper by Stevenson and Park. The effect of the insulation on the bottom of the slot is to move the core of the field a little and to decrease the inductance a trifle.

Figure 17 shows a slot occupied by 4 conductors which is part of a short pitch winding. The 2 conductors on the right carry +200 amperes each. The upper left-hand conductor carries no current, the lower left-hand carries a current of −200 amperes. The main field is vertical and reverses at the level H. The compensating field is horizontal and is that of a short transformer coil as in figure 12. The example is included for illustration of the degree of complexity of the field which is solvable by the method proposed.

The author has not been able to apply the method with assurance to core type transformer coils, or to high voltage shell type transformers, in which the length of primary and secondary coils is different. These are cases which are treated by Rogowski.

Appendix

Allusion has been made to "divergence" and "curl" in a number of parts of the paper. In order to make the material more complete and in order to verify curl of fields in the section on resolving a field into

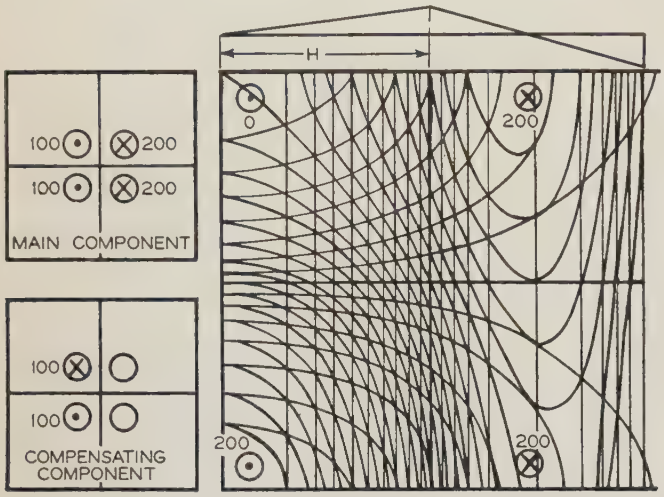


Fig. 17. Field in slot with short pitch winding

its components, the following general differential equations are given. Let V be the potential where there is any and let ϕ, B_x, x, y, and U have meanings before given, then

$$B_x = \frac{d\phi}{dy};\ B_y = -\frac{d\phi}{dx};\ \frac{dB_x}{dx} + \frac{dB_y}{dy} = \text{Divergence } B = 0$$

$$B_x = -\frac{dV}{dx};\ B_y = -\frac{dV}{dy};\ \frac{dB_x}{dy} - \frac{dB_y}{dx} = 3.2U = \text{Curl } B.$$

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The Status of Television in Europe

Television is being actively promoted in several European countries, principally Great Britain and Germany. In order to make available to individuals in the United States the present status of television in Europe, the U.S. Department of Commerce sent Andrew W. Cruse on a 2 months' study of television developments in England, Germany, and France. The article which follows is based upon an address delivered by Mr. Cruse upon his return.

IT was early in 1925 that Baird in England and Jenkins in the United States succeeded in demonstrating the practicability of television and almost hourly since then the statement has been made that "television in the home is just around the corner!" For some unaccountable reason this mirage of visual transmissions which has been dangled before the eyes of the public has failed to lose its novelty despite this repetition—and any writer has always been sure of attracting a large number of readers through the simple expedient of developing a new angle on the "television story."

On May 14, 1934 a new note crept into this ever-recurring "television story," when the British House of Commons announced the appointment of a committee:

To consider the development of television and to advise the Postmaster General on the relative merits of the several systems and on the conditions under which any public service of television should be provided.

This theme was built up to a terrific crescendo when, on January 14, 1935 the British television committee rendered its report. The corner had been turned, the public cheered, television stocks boomed—in short, a scientific sensation was created.

But in the background of the cheers in the United States could be heard the voices of those incredulous persons who were—and for that matter still are—demanding the answers to their questions: "What are *we* going to do about it? When are *we* going to have television in *our* homes? What is to be *our* answer to this challenge of our recognized leadership in the field of science?"

Based upon an address delivered by Andrew W. Cruse, chief, electrical equipment division, Bureau of Foreign and Domestic Commerce, U.S. Department of Commerce before the thirteenth annual convention of the National Association of Broadcasters, Colorado Springs, Colo., July 8, 1935. Manuscript received July 8, 1935; released for publication July 24, 1935.

That, in brief, was the situation when early in May 1935 the United States Department of Commerce decided to make a study of the television situation in Europe—because by this time Germany and France were also in the television picture—and advise the electrical and radio industries in this country on the exact state of affairs in a fair, unvarnished, uncolored, unbiased fashion.

The facilities of the Bureau of Foreign and Domestic Commerce available abroad have made this study possible in so short a period of time. The bureau maintains commercial attaches in the principal countries of the world, and these offices together with the consular offices of the Department of State are of inestimable value to American business in general. After having studied all the available material on television abroad and having secured letters of introduction to the leaders in that field from the industry in this country, the commercial attaches in England, Germany, and France were advised and they proceeded to lay out a schedule of appointments for the author which utilized every minute of the time available.

Before discussing the development of European television in detail, first consider what is meant by development. This can be given by answering the questions:

1. How many hours of television programs are now being given daily?

2. How many people are looking at those programs and how popular are those programs?

3. What are the prospects for increasing the scope of this television service in the immediate future?

Developments in Great Britain

In England, the British Broadcasting Corporation is now offering low definition television programs lasting from $^1/_2$ to $^3/_4$ of an hour twice each week. These programs are transmitted on a wave length of 261 meters with the accompanying sound on 398 meters, using 2 broadcast transmitters, 1 for the picture and the other for the accompanying sound. The Baird system employing mechanical scanning giving a 30 line picture 12 frames per second is used for this purpose. The B.B.C. appears to be doing an excellent job on these programs and the author was pleasantly surprised to discover that despite the low definition and objectionable flicker these programs do have an entertainment value for short periods—perhaps of the order of $^1/_2$ hour. Live talent is used exclusively on these programs and everything from a condensed version of "Carmen" to vaudeville acts is offered.

In answer to a query regarding the number of television receiving sets in service in the British Isles estimates were received which ranged from zero to 10,000. The British Post Office, however, which is in the best position to make an estimate, gave the figure of less than 100. Please bear in mind that these B.B.C. low-definition programs which are offered twice weekly and received by a maximum of 100 receiving sets comprise the only public television service now being offered in Great Britain. Both the Baird Company and Electrical and Musical Industries (E.M.I.) are transmitting experimental high definition television but inasmuch as no high definition receiving sets can now be purchased, these transmissions can in no way be considered as a public service.

Now, as to the prospects for increasing the scope of British television in the near future. On June 7, 1935 the Postmaster General announced that he had received "a communication from the television advisory committee regarding the choice of a site for the projected London television station and other matters relative to the proposed experimental television service." It may be noted that the Postmaster General refers to this as the "proposed *experimental* television service." The announcement goes on to state that the Alexandra Palace has been selected as the location and that Baird and E.M.I. have been called upon to submit bids for the transmitters to be used at that location. There is no reason to doubt that these bids will be accepted and the chances are that late this winter or early next spring high definition television service will be inaugurated by B.B.C. using alternately the E.M.I. 405-line 50-frame interlaced and the Baird 240-line 25-frame sequential transmitters. It is now proposed to operate 1 hour each morning and 2 hours each evening using 6.6 meters for vision and 7.2 meters for the associated sound signals. High definition television receiving sets capable of receiving programs sent by either transmitter, i. e., Baird 240 line or E.M.I. 405 line, are expected to make an appearance about the time the bids for the transmitters are actually accepted—which will probably be some time this fall. It is anticipated that their minimum price will be the equivalent of $250.

Other British Developments

Experimental work is being carried on in the field of coaxial cables for the land line relay of television programs from one city to another and there is one unconfirmed report that the British Post Office hope to have a coaxial cable link between London and Birmingham before the New York-Philadelphia coaxial cable is placed in service. In view of the fact that they speak of their cable as being capable of handling a frequency band of but 1.5 megacycles, it may seriously be doubted if they can, or will, plan to use it for television relay work.

Their ultimate plans call for the erection of 12 transmitters to cover the principal population centers of Great Britain and it is confidently predicted that 4 or 5 of these will be in service by the end of 1937. The confidence of the prospective manufacturers of television receivers is reflected in their prediction that 50,000 of those sets will be in service by the end of 1936 and from 5 to 10 times that many more by the end of 1937.

In considering television the question logically arises: "Who is going to pay the bills?" It should be remembered that approximately 7 million listeners are now paying license fees of $2.50 per year of which the B.B.C. receives $1.12 and the balance goes to the treasury. It is now proposed to increase the

B.B.C. share of the license fee to $2.25, thus giving them approximately $15,750,000 annually on which to operate both sound and visual services. It is most interesting to note that this new proposal has caused practically no adverse criticism from license holders in areas not to be served by the television programs.

The British Broadcasting Corporation's charter expires December 31, 1936 and it is going to be most interesting to observe what effect this venture into this new field will have upon its future!

Developments in Germany

In Germany, 180-line 25-frame sequentially scanned transmissions are being given at the present time from a 7 meter transmitter in Berlin. The Broadcasting Company of the Ministry of Propaganda provides a 2 hour program 3 nights a week and the Post Office supplies programs in the mornings and afternoons and on alternate evenings. Several places are provided in Berlin where the public may view these programs and they are proving most popular. Inasmuch as practically all the program material is provided by films, repetition is not infrequent and occasionally an old film leaves much to be desired. Generally speaking, however, the quality of these transmissions is excellent and impresses one with the high entertainment value which can be secured with a 180 line picture.

While the German engineers expect to carry on their experiments using 180 lines, they plan to eventually go to 270 line pictures. This latter figure has been arrived at as the most economically satisfactory standard, taking into consideration transmission costs and land line relays using coaxial cable. They are confident of their ability to manufacture long haul cables of this character capable of handling a band of 3 megacycles. The maximum frequency band which they have been able to handle by cable so far is 5 megacycles and that, they quite frankly admit, could only be accomplished over a distance of approximately 100 meters. The Post Office is considering the laying of a 3 megacycle cable between Berlin and Frankfort and expects to use this cable for the relay of television programs.

The German Ministry of Propaganda is most interested in securing broadcast coverage in those areas which are now in "dead spots." In view of the fact that practically all of the frequency bands available to that country are now in use, they expect to cover those "dead spot" areas with ultra-short wave, probably using 7 meters, and equipping each new location with both sound and television transmitters at the same time. In order to secure television coverage of the principal population centers of the entire country it is estimated that 25 20-kw ultra-short wave transmitters will be required. A survey of the locations of these transmitters has already been started using a full power (20 kw) "transportable" transmitter for both sound and television. This "transportable" transmitter was built by Telefunken and is mounted on several large trucks—one truck carrying a Diesel driven power plant. It is anticipated that these field strength surveys will require approximately 2 weeks for each locality and as soon as a locality has been approved, work on the permanent transmitter will be started.

Future of Television Sales in Germany

At the present time no high definition television receivers are being sold, but all of the principal manufacturers are planning to show models and offer them for sale during the summer of 1935. The manufacturers would really prefer to have the transmission standards raised to 270 lines before offering their sets for sale because they feel that the 180 line work is not sufficiently good to stimulate sales. As a matter of fact, they are only estimating their 1935 sales to be 1,000 receivers in the Berlin area where the present television programs are covering an area occupied by a population of 7 million. A patent pool is being formed and negotiations in this direction are proceeding very smoothly indeed. While natural competition exists between the various German radio manufacturers, they seem to be able to get together in the solution of their mutual problems in a very commendable fashion. It is anticipated that television receivers which will be adaptable to the 270 line standard will sell for from $240 to $500. In order to get these prices reduced as quickly as possible, the Loewe Company has already laid out an assembly line and are ready to go into quantity production in a very short time.

The Broadcasting Company has a very interesting piece of equipment which it calls its television truck and which is used to cover news events. This truck, which was first used at the May Day ceremony at the Templehof Aerodrome at which Chancellor Hitler spoke, consists of a low-powered ultra-short wave transmitter for both sound and television using the intermediate film method. The program is relayed by the high powered Berlin transmitter and the transmission was declared most satisfactory by people who saw it. The interval of delay between the taking of the picture by the camera mounted on top of the truck and the time when that picture has been televised is approximately 90 seconds. The Broadcasting Company engineers feel that the high speed with which it is necessary to develop and fix the film does not give a satisfactory sound track and are consequently preparing to record the sound by the steel tape method developed recently by the Lorenz Company.

Television is moving ahead in Germany on what certainly appears to be a most thorough basis and the cost is being carried by the license fees plus an additional governmental appropriation.

Developments in Other Countries

In France, the Ministry of Posts and Telegraphs is extremely interested in having that country match the television developments in England and Germany and is doing everything in its power to speed up this work realizing that France is behind those 2 countries in this respect. It has started experimental 60-line 25-frame transmissions on 175 meters but no regular schedule is maintained. The French

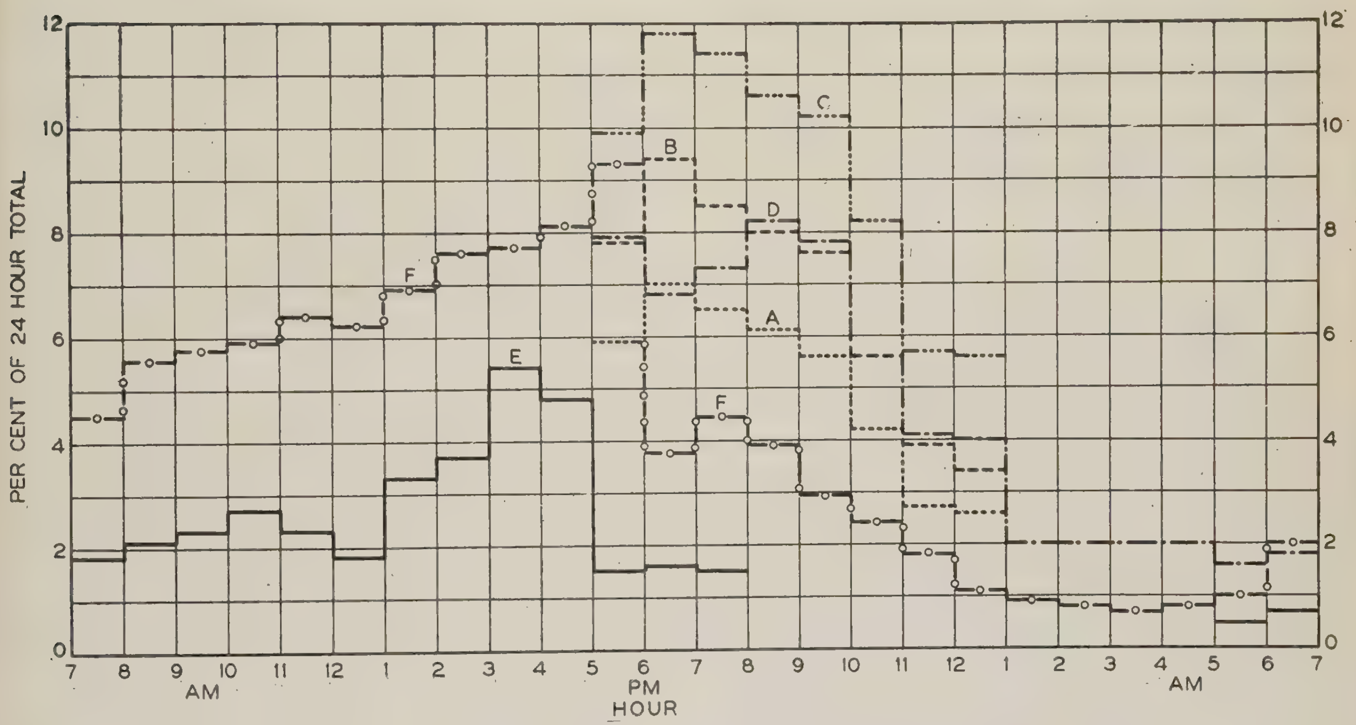
hope to be able to go to 90 lines and then to 180 lines as quickly as practicable but it may be seriously doubted whether much progress in this direction will be made before 1936.

Some work is being carried on in other European countries, notably Russia and Italy. So far these developments do not appear to have progressed very far—but, an entirely different picture should present itself in the next 2 years, particularly in England and Germany.

Regarding the future of television in the United States, we should not only continue along our present line, but in addition should observe the European picture closely. The technical development of television is still in a state of flux and much work in the laboratory still remains to be done. Also, the broadcasting industry must develop studio technique before it can hope to enter this field satisfactorily.

In Europe, the governments are directly or indirectly supporting and operating broadcasting and television; in the United States it is the author's belief that the interests of both broadcasting and television can best be served without government assistance. With business recovery and the development of the technical features, it will undoubtedly be possible to add television to the present broadcasting service and present television programs in the same thorough fashion in which broadcasts are now being presented.

The Important Rôle Played by Street Lighting in Automobile Fatalities



THE important rôle played by street lighting in automobile fatalities on city thoroughfares is depicted graphically in the accompanying chart, which has been prepared for the A.I.E.E. committee on production and application of light by R. E. Simpson (A'16) illuminating engineer, National Bureau of Casualty and Surety Underwriters, West Hartford, Conn. The percentage of day fatalities (line *E*) consistently is below the percentage of day traffic (line *F*), the ratio averaging 1 to 3, while during the hours of darkness this ratio is reversed as indicated by line *D*. During part of the year the hours from 5 to 8 p.m. and from 5 to 7 a.m. are daylight hours, and during the rest of the year they are dusk or darkness hours. Lines *D* and *E* overlap during these hours so that to obtain the total percentage of fatalaties for the year during these hours the percentages for the 2 lines must be added; for example, the percentage of fatalities from 6 to 7 p.m. when this is a daylight hour, is 1.6, and 6.8 when it is a dark hour, or a total of 8.4 during the entire year. The grades of lighting *A*, *B*, and *C* (lines *A*, *B*, and *C*, respectively) correspond to the minimum requirements of the street lighting code of the Illuminating Engineering Society for heavy, medium, and light traffic thoroughfares, respectively. It is noteworthy that as the level of street illumination decreases the percentage of fatalities increases. The night fatalities for all cities (line *D*) between the hours of 1 and 5 a.m. are grouped.

Current and Voltage Loci in 3-Phase Y-Y Circuits

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Engineers often find it convenient to be able to determine the various currents and voltages in an electrical system not merely for one fixed condition, but for any value of any impedance element from zero to infinity. In an effort to facilitate such computations, the method presented in this paper has been developed. Although the method as presented is applied specifically to the star-star (Y-Y) circuit, the treatment is said to be applicable also to other circuits. All voltages and currents in this circuit are shown to follow circular loci when any self-impedance is varied; these loci are determined by the use of a circle in the form of a linear fractional transformation. The practical application of the method is illustrated by numerical examples.

SOLUTION of unbalanced polyphase circuits comprises an extensive literature in network theory. At the very outset it was realized that the application of Ohm's and Kirchoff's Laws to obtain the requisite number of simultaneous equations and their solution was too cumbersome and time consuming for practical work. The importance of determining the performance of unbalanced systems was responsible for the development of different types of solutions, each having for its purpose the evaluation of the various currents and voltages without resorting to the lengthy equations of the classical method. The conception of symmetrical components by Fortescue[1] supplied a convenient and powerful tool for handling unbalanced conditions, capable of very general application. Various special methods have been described which are applicable to particular kinds of circuits—for example, the superposition of a reversed neutral voltage in a star circuit by Karapetoff.[2]

Frequently the solution of an unbalanced polyphase circuit is facilitated by the presence of a short circuit or an open circuit in one or more phases, which simplifies the network. However, where severely unbalanced conditions exist (for instance, a heavy single phase load such as an arc furnace), there is no network simplification and the system must be solved by the most appropriate method available, depending upon the type of connection. The numerical solution is valid for one particular condition of the load; and if it were desired to determine the performance of a network as the load or some other impedance varied, the problem would have to be solved point by point.

It is the object of this paper to show that in any star-star circuit, with or without neutral connection, with any values of linear and bilateral self- and mutual impedances in the phases of source and load and in the interconnecting lines, with internal voltages in the source and load phases of any value, all currents and voltages, the symmetrical components of voltages and currents, and the unbalance factors of the symmetrical components may be determined readily with a minimum of computation as a function of any self-impedance in the network. The treatment also can be extended to other types of connections.

It will be demonstrated that the currents and voltages follow circular loci when any self-impedance is varied along a straight line in the complex plane. Hence the solution resolves itself into the evaluation of 3 points of the desired quantity in order to determine the circle. For this purpose, it is convenient to consider the circle as a linear fractional transformation, as originally applied to alternating current problems by Schenkel.[3] The Schenkel form is

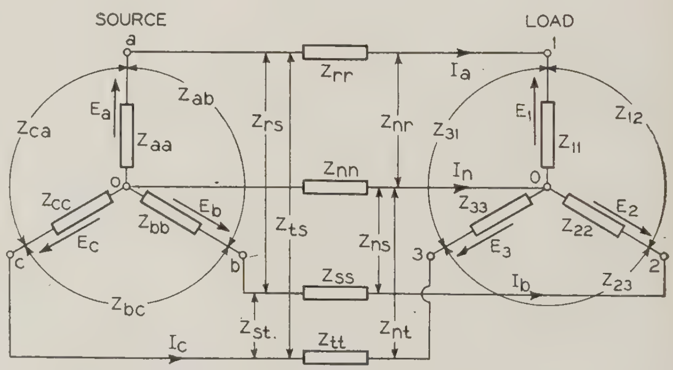

Fig. 1. Schematic diagram of general star-star circuit

$$S = \frac{\alpha + \beta\rho}{\gamma + \delta\rho} \tag{1}$$

in which S is a vector describing a circle as the scalar variable, ρ ranges from minus to plus infinity, and α, β, γ, and δ are complex constants. The radius

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1. For all numbered references see list at end of paper.

and the center vector may be evaluated in terms of these constants, using expressions developed by Schumann.[4] Generally, however, it will be found more expedient to determine the invariant points of the circle, namely, when $\rho = 0$ and when $\rho = \infty$, and use for the third point any convenient value of ρ. These 3 points suffice not only to locate the circle, but also to fix the linear scale line that connects points on the circle with corresponding values of the variable ρ. With the scale line drawn, the value of S may be read off the plot in magnitude and phase angle for any value, positive or negative, of the variable scalar. The construction of the circle and the scale line has been described in a previous paper.[5]

The fundamental current equations in the form of linear fractional transformations are given in detail for the star-star circuit, with and without mutual impedances. The corresponding current equations for a star connected load with constant applied voltages at the sending end may be obtained directly by dropping the terms involving the internal impedances of the source and considering the internal voltages of the source phases to be the applied voltages.

General Solution, Without Mutual Impedances

The circuit that will be studied is a star-star connection tied through line and neutral impedances as shown in figure 1. At first no mutual impedances will be considered between any of the circuit elements. The self impedances are subject to no restriction, with the exception that they be linear and bilateral. The frequency will be maintained constant, and for greatest generality internal voltages of any magnitude and phase will be assumed to exist in both the source and load phases.

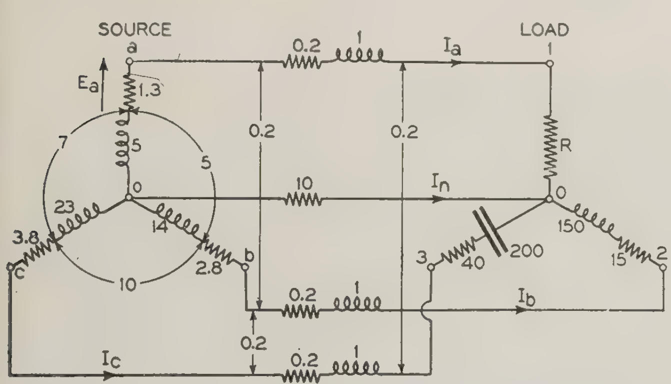


Fig. 2. Specific star-star circuit for which current and voltage loci are shown in succeeding figures

All circuit constants are in ohms

Writing the electromotive force equations for the various meshes and eliminating the neutral current,

$$I_a(Z_{aa} + Z_{rr} + Z_{11} + Z_{nn}) + I_bZ_{nn} + I_cZ_{nn} = E_a - E_1 \quad (2)$$

$$I_aZ_{nn} + I_b(Z_{bb} + Z_{ss} + Z_{22} + Z_{nn}) + I_cZ_{nn} = E_b - E_2 \quad (3)$$

$$I_aZ_{nn} + I_bZ_{nn} + I_c(Z_{cc} + Z_{tt} + Z_{33} + Z_{nn}) = E_c - E_3 \quad (4)$$

Solutions for the 3 line currents may be written in the form

$$I_a = \frac{\Delta I_a}{\Delta_s} \qquad I_b = \frac{\Delta I_b}{\Delta_s} \qquad I_c = \frac{\Delta I_c}{\Delta_s} \quad (5)$$

The numerators are:

$$\Delta I_a = (E_a - E_1)(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + Z_{nn}[(E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22}) - (E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{tt} + Z_{33})] \quad (6)$$

$$\Delta I_b = (E_b - E_2)(Z_{cc} + Z_{tt} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11}) + Z_{nn}[(E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{tt} + Z_{33}) - (E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11})] \quad (7)$$

$$\Delta I_c = (E_c - E_3)(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + Z_{nn}[(E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11}) - (E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22})] \quad (8)$$

The common denominator of the expression for line currents is:

$$\Delta_s = (Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + Z_{nn}[(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + (Z_{cc} + Z_{tt} + Z_{33}) \times (Z_{aa} + Z_{rr} + Z_{11})] \quad (9)$$

The impedance elements will be considered as varying: (1) along the resistance component, (2) along the quadrature component, and (3) in magnitude at constant phase angle. Inspection of the equations for line currents discloses all the numerators and the common denominator to be linear with respect to any one impedance element. Therefore with any one of the impedances considered variable, the remaining impedances being considered constant, each numerator and the denominator may be written as a constant term plus a variable term. Hence, whichever impedance be chosen as the variable, the 3 expressions for line currents readily may be rewritten in the canonical form of a circle. Moreover, the neutral current, being a summation of the 3 line currents, likewise follows a circular locus because the numerators may be added directly, the denominator remaining unchanged. Thus

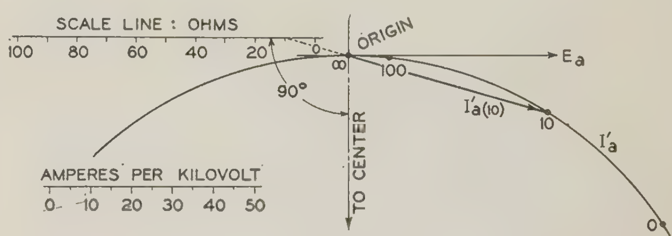


Fig. 3. Locus of line current I_a' of circuit of figure 2 without mutual impedances

$$I_n = -(I_a + I_b + I_c) \quad (10)$$

Writing the neutral current as $I_n = (\Delta I_n)/\Delta_s$ and substituting the line current expressions into equation 10,

$$\Delta I_n = (E_a - E_1)(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + (E_b - E_2)(Z_{cc} + Z_{tt} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11}) + (E_c - E_3)(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) \quad (11)$$

When there is no neutral connection, making Z_{nn} infinite in equations 5,

$$I_a = \frac{(E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22}) - (E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{tt} + Z_{33})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + (Z_{cc} + Z_{tt} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11})} \quad (12)$$

$$I_b = \frac{(E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{tt} + Z_{33}) - (E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + (Z_{cc} + Z_{tt} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11})} \quad (13)$$

$$I_c = \frac{(E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11}) - (E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{tt} + Z_{33}) + (Z_{cc} + Z_{tt} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11})} \quad (14)$$

Thus the loci of the line currents remain circular.

When the neutral impedance is zero, the following equations are obtained from equations 5

$$I_a = \frac{E_a - E_1}{Z_{aa} + Z_{rr} + Z_{11}} \quad (15)$$

$$I_b = \frac{E_b - E_2}{Z_{bb} + Z_{ss} + Z_{22}} \quad (16)$$

$$I_c = \frac{E_c - E_3}{Z_{cc} + Z_{tt} + Z_{33}} \quad (17)$$

Under this condition, 2 of the circular loci degenerate into points, that is, constants, or circles of zero radius. For instance if Z_{11} were taken as the variable impedance, I_a would be a circle and I_b and I_c would be constants.

Voltages. The process of evaluating voltages is simply that of adding potential differences between those points in the system across which the voltage is desired. This addition involves only the summation of internal voltages, which are constants, and impedance drops. Reverting to the original set of current equations (5) and the numerator expressions, equations 6, 7, and 8, it may be observed that the numerator of any current equation is free of all impedance elements through which the current flows.

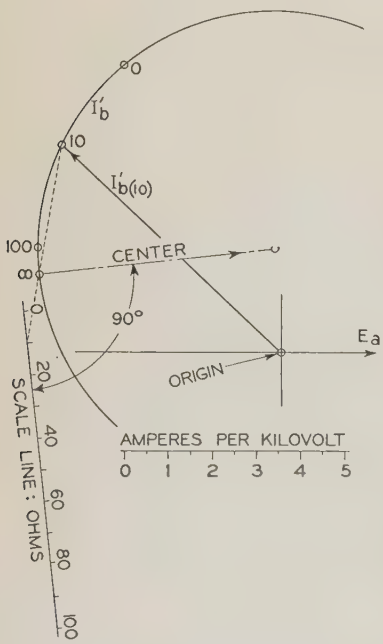


Fig. 4. Locus of line current I_b' of circuit of figure 2 without mutual impedances

Therefore, the multiplication of any current expression by any impedance to give an actual impedance drop existing in the system does not disturb the linearity of any numerator with respect to any impedance. The denominator being common, any summation of existing impedance drops is obtained by direct addition of the numerators of the currents multiplied by the impedances through which they flow. Thus it immediately follows that the loci of all phase and line voltages, voltage between neutral points, and line voltage drops are circular when any one impedance is varied. For example, the voltage across phase 1 of the load is I_aZ_{11}. Let the variable impedance be Z_{11}. The expression for I_a does not contain Z_{11} in the numerator and thus I_aZ_{11} remains a linear fractional transformation.

The expressions for the line currents are the 3 fundamental equations for this type of solution. Once these expressions are evaluated, since the denominators are alike, the calculation of any voltage in the circuit is effected by multiplication of the numerators of the currents by the proper impedances. It is not necessary to substitute into detailed expressions for voltages since that work has already been done in obtaining the expressions for currents.

Symmetrical Components. Bearing in mind that symmetrical components of currents and voltages are summations of actual currents and voltages multiplied by the sequence operators, it is evident that all symmetrical components of the circuit likewise follow circular loci. The same holds true for the unbalance factors, that is, the ratios of negative and zero sequence to positive sequence amplitudes of currents and voltages.

Numerical Example, Without Mutual Impedances

Simplicity and economy of computation entailed in computing the currents and voltages as a circular function of one of the impedances may be illustrated best by a numerical solution of an actual circuit. To demonstrate that this method of solution is unencumbered by lengthy computations, even in the most unbalanced of systems, a circuit will be considered in which the 3 phases of the load are a pure resistance, an impure inductance, and an impure capacitance, respectively. The phases of the source will be considered to have unequal values of inductive impedance, and the neutral to possess an appreciable resistance. The impedances of the connecting lines will be considered to be inductive and equal; the internal voltages at the source will be considered to be balanced, and no internal voltages will be assumed to exist in the load phases.

The constants of the circuit will be as follows:

$Z_{aa} = 1.3 + j5.0$ ohms $\qquad Z_{11} = R + j0$ ohms
$Z_{bb} = 2.8 + j14.0$ ohms $\qquad Z_{22} = 15 + j150$ ohms
$Z_{cc} = 3.8 + j23.0$ ohms $\qquad Z_{33} = 40 - j200$ ohms
$Z_{rr} = Z_{ss} = Z_{tt} = 0.2 + j1.0$ ohms
$Z_{nn} = 10 + j0$ ohms

This circuit is shown in figure 2; the mutual impedances indicated will be treated later and will not be considered to exist at present. The resistance arm of the load, Z_{11}, will be taken as the variable impedance, and the loci of currents and voltages will be determined for a variation of $R = Z_{11}$ between zero and infinity. Merely enough unequal elements have been introduced into this problem to indicate the generality of the method. Inspection of the preceding equations shows that if, in addition, the internal voltages at the source had been assumed to be unbalanced and internal voltages assumed to exist in the load, the result would have been merely a modification in the constants of the current equations. The same holds true for inequality of line impedances.

The internal voltage E_a will be considered as the reference vector and all quantities will be evaluated

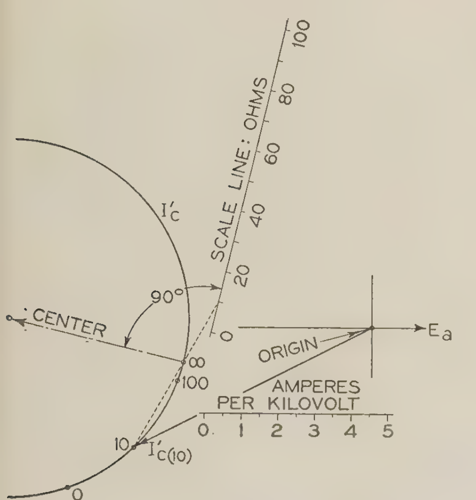


Fig. 5. Locus of line current I_c' of circuit of figure 2 without mutual impedances

in terms of amperes or volts per volt of internal voltage E_a. To prevent any confusion all unit quantities will be indicated by a prime ($'$). Substituting the constants of this problem into equations 5, the following expressions are obtained for the line currents:

$$I_a' = \frac{33{,}970\angle 7.0°}{393{,}900\angle 35.7° + R \times 30{,}710\angle 7.4°} \text{ amperes per volt} \quad (18)$$

$$I_b' = \frac{2{,}927\angle 154.5° + R \times 177.4\angle 169.4°}{393{,}900\angle 35.7° + R \times 30{,}710\angle 7.4°} \text{ amperes per volt} \quad (19)$$

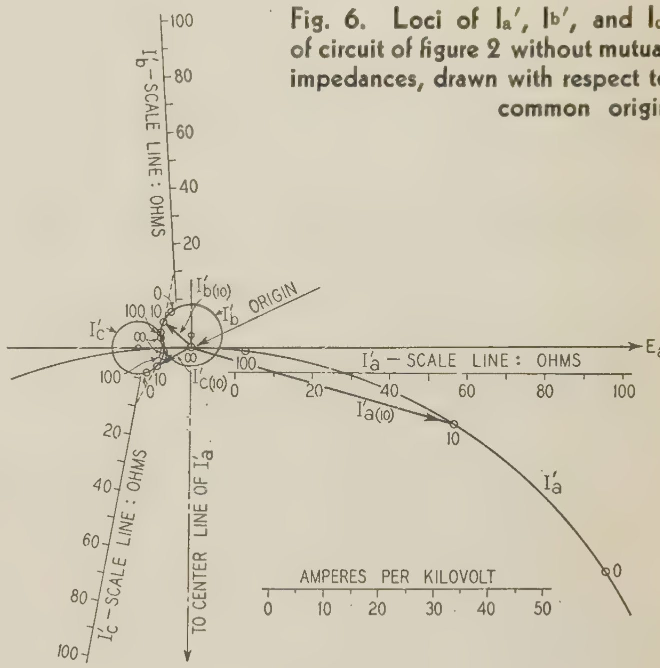
$$I_c' = \frac{3{,}688\angle -116.2° + R \times 159.8\angle -161.9}{393{,}900\angle 35.7° + R \times 30{,}710\angle 7.4°} \text{ amperes per volt} \quad (20)$$

The 3 loci now are determined by evaluating equations 18, 19, and 20 for 3 points: $R = 0$, $R = \infty$, and $R =$ some other value, for example, 10 ohms. The corresponding values of line currents (in amperes per kilovolt) are found to be as follows:

	$R = 0$	$R = 10$	$R = \infty$
I_a'	86.24 $\angle -28.6°$	49.94 $\angle -16.3°$	0
I_b'	7.431 $\angle 118.8°$	6.856 $\angle 136.8°$	5.778 $\angle 162.0°$
I_c'	9.362 $\angle -151.8°$	7.258 $\angle -152.9°$	5.203 $\angle -169.4°$

These points are also sufficient to determine the scale lines of the circles. The resultant loci are drawn in figures 3, 4, and 5. The construction of the scale lines is indicated as well as the location of 4 points on each circle corresponding to 0, 10, 100, and ∞ ohms for R. Dotted lines are shown connecting the scale lines with the point on each circle corre-

Fig. 6. Loci of I_a', I_b', and I_c' of circuit of figure 2 without mutual impedances, drawn with respect to common origin



sponding to 10 ohms. The corresponding current vector drawn from the origin, as shown, then represents the value of current in magnitude and phase for 10 ohms. The 3 current loci are drawn with respect to a common origin in figure 6 to give a better picture of the relationship of the currents. This figure, as a consequence of the considerable reduction in size for reproduction and the small scales of I_b' and I_c' as compared with that of I_a', is not as suitable for quantitative work as the preceding figures, but it does give a more comprehensive representation of the simultaneous variation of the currents in the various phases.

By substituting the current expressions in equations 18, 19, and 20 into equation 10 the neutral current assumes the following form:

$$I_n' = \frac{29{,}520\angle -177.0° + R \times 326.8\angle 3.0°}{393{,}900\angle 35.7° + R \times 30{,}710\angle 7.4°} \text{ amperes per volt} \quad (21)$$

The 3 points necessary to determine the neutral current locus, for the same values of resistance as before, are

for $R = 0$ $\quad I_n' = 74.95\angle 147.3°$ amperes per kilovolt
for $R = 10$ $\quad I_n' = 38.60\angle 160.9°$ amperes per kilovolt
for $R = \infty$ $\quad I_n' = 10.64\angle -4.5°$ amperes per kilovolt

The locus of neutral current is plotted in figure 7 with the same details shown as for the line currents. It is not necessary to use the expression for neutral current directly as given in equation 10 to evaluate the 3 points of the circle if instead the specific values of line currents obtained for different values of R are added.

With all the current loci determined, any voltage circle now may be located by taking the proper impedance drops. For example, the voltage across phase 1 of the load is

$$V_{01}' = RI_a' = \frac{R \times 33{,}970 \angle 7.0°}{393{,}900 \angle 35.7° + R \times 30{,}710 \angle 7.4°} \text{ volts per volt} \quad (22)$$

which gives

for $R = 0$ $\quad V_{01}' = 0$ volts per volt
for $R = 10$ $\quad V_{01}' = 0.4994 \angle -16.3°$ volts per volt
for $R = \infty$ $\quad V_{01}' = 1.106 \angle -0.4°$ volts per volt

The locus of V_{01}' is given in figure 8. In a similar manner the voltages across the remaining phases of the load would be

$$V_{02}' = Z_{22}I_b' = \frac{441{,}200 \angle -121.2° + R \times 26{,}750 \angle -106.3°}{393{,}900 \angle 35.7° + R \times 30{,}710 \angle 7.4°} \text{ volts per volt} \quad (23)$$

and

$$V_{03}' = Z_{33}I_c' = \frac{752{,}100 \angle 165.1° + R \times 32{,}590 \angle 119.4°}{393{,}900 \angle 35.7° + R \times 30{,}710 \angle 7.4°} \text{ volts per volt} \quad (24)$$

Likewise the voltage across the neutral is

$$V_{00}' = Z_{nn}I_n' = \frac{295{,}200 \angle -177.0° + R \times 3{,}268 \angle 3.0°}{393{,}900 \angle 35.7° + R \times 30{,}710 \angle 7.4°} \text{ volts per volt} \quad (25)$$

The symmetrical components of the line currents are determined by the following relationships:

$$I^0 = \frac{1}{3}(I_a + I_b + I_c) \quad (26)$$

$$I^+ = \frac{1}{3}(I_a + \sigma I_b + \sigma^2 I_c) \quad (27)$$

$$I^- = \frac{1}{3}(I_a + \sigma^2 I_b + \sigma I_c) \quad (28)$$

in which the sequence operators are $\sigma = 1\angle 120°$ and $\sigma^2 = 1\angle 240°$. To obtain these loci it is necessary only to go back to the specific values of line currents evaluated at the beginning of the solution and operate on the points with 1, σ, and σ^2. Combining terms in this manner, the values of the symmetrical components of currents (in amperes per kilovolt) for 0, 10, and ∞ ohms in Z_{11} become:

	$R = 0$	$R = 10$	$R = \infty$
$I^{0\prime}$	$24.98 \angle -31.6°$	$12.87 \angle -19.1°$	$3.547 \angle 175.5°$
$I^{+\prime}$	$27.37 \angle -28.0°$	$16.21 \angle -16.1°$	$1.006 \angle -14.3°$
$I^{-\prime}$	$33.93 \angle -27.0°$	$20.89 \angle -14.8°$	$2.561 \angle -0.6°$

The loci of $I^{0\prime}$, $I^{+\prime}$, and $I^{-\prime}$ are drawn in figure 9 with construction details as before. Dividing $I^{0\prime}$ and $I^{-\prime}$, respectively, by $I^{+\prime}$ at $R = 0$, 10, and ∞ would determine the circular loci of the 2 current unbalance factors. The symmetrical components of the voltages are handled similarly.

General Solution, With Mutual Impedances

When a star-star circuit contains mutual impedances, the same analysis may be followed as outlined for the circuit with self-impedances only. As in the star-star circuit with self-impedances only the most general form of circuit involving mutual impedances will be treated. As shown in figure 1, mutual impedances among the several phases of the source, among the several phases of the load, and among the several connecting lines including the neutral, are assumed to exist. The mutual impedances are designated with subscripts representing the interacting elements. Internal voltages of any magnitude and phase at both source and load are assumed as before, and the frequency is assumed to be constant. Both self- and mutual impedances are considered to be linear and bilateral.

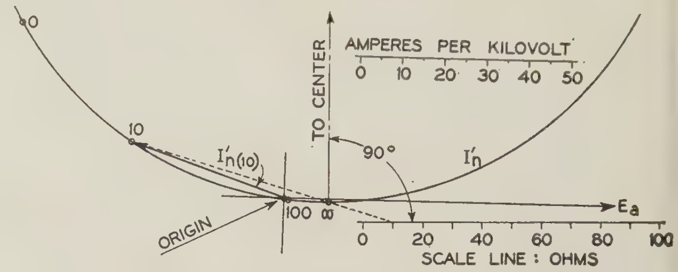


Fig. 7. Locus of neutral current (I_n') of circuit of figure 2 without mutual impedances

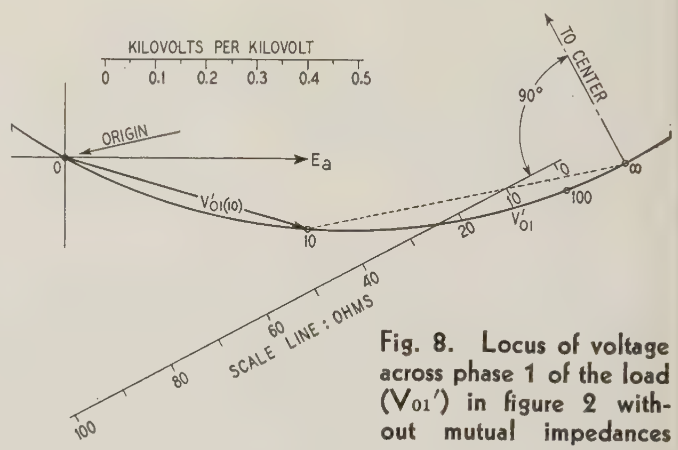


Fig. 8. Locus of voltage across phase 1 of the load (V_{01}') in figure 2 without mutual impedances

Writing the electromotive force equations for this circuit corresponding to the group of equations 2, 3, and 4, and eliminating the neutral current,

$$I_aA_1 + I_bB_1 + I_cC_1 = E_a - E_1 = K_1$$
$$I_aA_2 + I_bB_2 + I_cC_2 = E_b - E_2 = K_2$$
$$I_aA_3 + I_bB_3 + I_cC_3 = E_c - E_3 = K_3$$

The A's, B's, and C's represent linear summations of self- and mutual impedances. If these equations be written out term by term it may be observed that

$$B_1 = A_2 \qquad C_1 = A_3 \qquad C_2 = B_3$$

Making the substitutions indicated, the electromotive force equations may be rewritten in the form

$$I_aA_1 + I_bA_2 + I_cA_3 = K_1 \quad (29)$$
$$I_aA_2 + I_bB_2 + I_cB_3 = K_2 \quad (30)$$
$$I_aA_3 + I_bB_3 + I_cC_3 = K_3 \quad (31)$$

The various coefficients of the currents in equations 29, 30, and 31 are:

$$A_1 = Z_{aa} + Z_{rr} + Z_{11} + Z_{nn} - 2Z_{nr} \quad (32)$$
$$B_2 = Z_{bb} + Z_{ss} + Z_{22} + Z_{nn} - 2Z_{ns} \quad (33)$$
$$C_3 = Z_{cc} + Z_{tt} + Z_{33} + Z_{nn} - 2Z_{nt} \quad (34)$$

$$A_2 = Z_{ab} + Z_{rs} + Z_{12} + Z_{nn} - Z_{nr} - Z_{ns} \quad (35)$$
$$B_3 = Z_{bc} + Z_{st} + Z_{23} + Z_{nn} - Z_{ns} - Z_{nt} \quad (36)$$
$$A_3 = Z_{ca} + Z_{tr} + Z_{31} + Z_{nn} - Z_{nt} - Z_{nr} \quad (37)$$

For convenience the solutions of the currents may be expressed as

$$I_a = \frac{\Delta I_a}{\Delta_m} \qquad I_b = \frac{\Delta I_b}{\Delta_m} \qquad I_c = \frac{\Delta I_c}{\Delta_m} \quad (38)$$

The numerators of these expressions are as follows:

$$\Delta I_a = K_1(B_2C_3 - B_3^2) + K_2(A_3B_3 - A_2C_3) + K_3(A_2B_3 - A_3B_2) \quad (39)$$
$$\Delta I_b = K_1(A_3B_3 - A_2C_3) + K_2(A_1C_3 - A_3^2) + K_3(A_2A_3 - A_1B_3) \quad (40)$$
$$\Delta I_c = K_1(A_2B_3 - B_2A_3) + K_2(A_2A_3 - A_1B_3) + K_3(A_1B_2 - A_2^2) \quad (41)$$

and the common denominator is

$$\Delta_m = A_1B_2C_3 - A_1B_3^2 - B_2A_3^2 - C_3A_2^2 + 2A_2A_3B_3 \quad (42)$$

If the numerators and the denominator be examined term by term after substituting the values of the coefficients as given in equations 32 to 37 it may be found that:

1. The denominator is linear with respect to all self- and mutual impedances.
2. The numerator of any current equation is linear with respect to all self-impedances.
3. No numerator of any current equation contains any self-impedances through which the current flows, or any mutual impedances connecting any element through which the current flows.
4. The numerator of any current equation contains squares of all mutual impedances in the circuit except those connecting any element through which the current flows.

These observations indicate that with fixed mutual impedances any current in the system may be written as a linear fractional transformation with any one self-impedance considered as a variable. Any current thus is seen to be a circular function of any self-impedance in the circuit.

The voltage across any part of the system consists of the summation of internal voltages and impedance drops between the 2 points under consideration. For example, the voltage across phase 1 of the load is V_{01} which is

$$V_{01} = E_1 + I_aZ_{11} + I_bZ_{12} + I_cZ_{31} \quad (43)$$

If the mutual impedances remain fixed and one of the self-impedances such as Z_{11} be considered as the variable, I_a, I_b, and I_c all will follow circular loci. Since Z_{11} does not enter into the numerator of the expression for I_a, I_aZ_{11} remains a linear fractional transformation. Likewise, Z_{12} and Z_{31} being constants, the linearity of I_bZ_{12} and I_cZ_{31} with respect to Z_{11} is not disturbed. The denominator of all current expressions being common, the summation of I_aZ_{11}, I_bZ_{12}, and I_cZ_{31} is merely another linear fractional transformation which when added to the constant E_1 produces the voltage V_{01} across phase 1 of the load. Therefore, with fixed mutual impedances the voltage in any part of the system follows a circular locus when any one self-impedance is varied.

Since both currents and voltages in a star-star circuit with mutual impedances may be represented by a linear fractional transformation when any self-impedance varies, and the denominator of all current and voltage expressions is common, it follows that the symmetrical components and their unbalance factors likewise follow circular loci.

Thus, the circuit with mutual impedances succumbs to precisely the same treatment as applied to circuits containing self-impedances only. The presence of mutual impedances, however, does impose a restriction: The currents and voltages follow circular loci when any self-impedance is considered as the variable, but not when a mutual impedance is varied. Since squares of mutual impedance terms appear in the numerators of the current expressions, a variation of a mutual impedance would engender

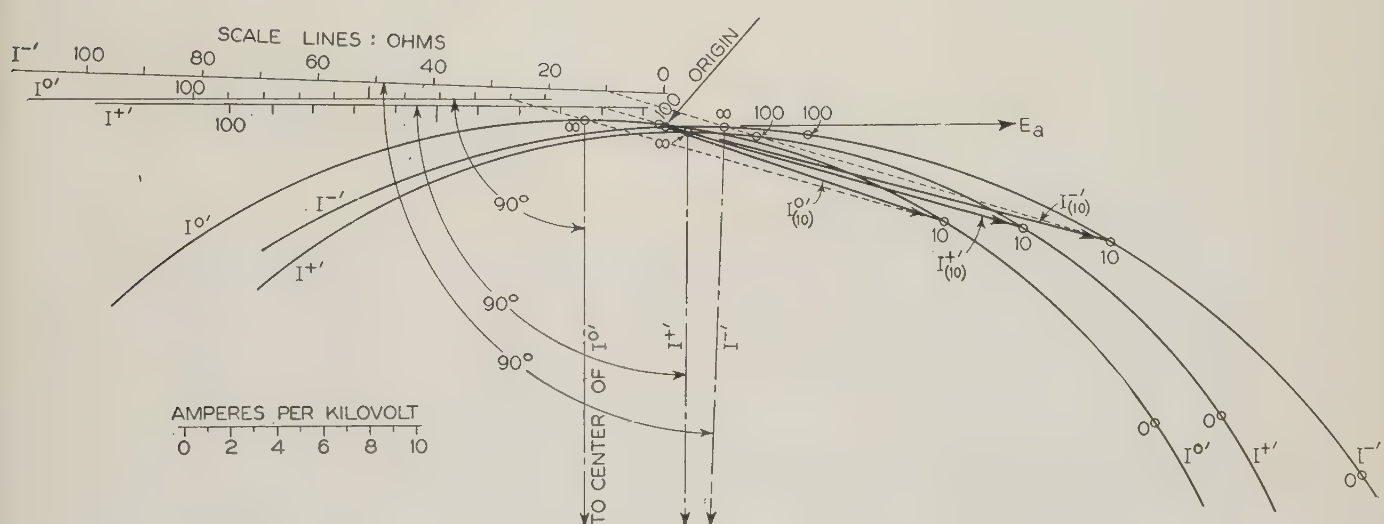


Fig. 9. Loci of the symmetrical components of current in circuit of figure 2 without mutual impedances

loci of higher order which will not be treated in the present paper.

Numerical Solution, With Mutual Impedances

To illustrate the application of the 3 point method to the evaluation of circular loci when mutual impedances are present, the same circuit will be employed as in the preceding example with the addition of the following mutual coefficients in the source phases and in the connecting lines:

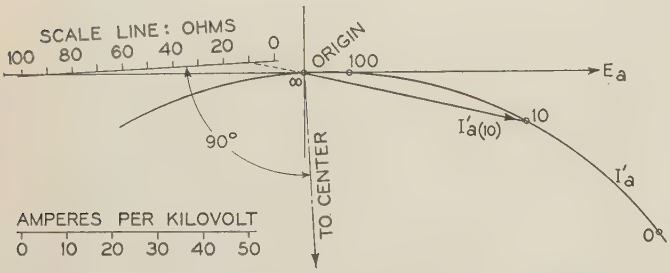


Fig. 10. Locus of line current I_a' of circuit of figure 2 with mutual impedances

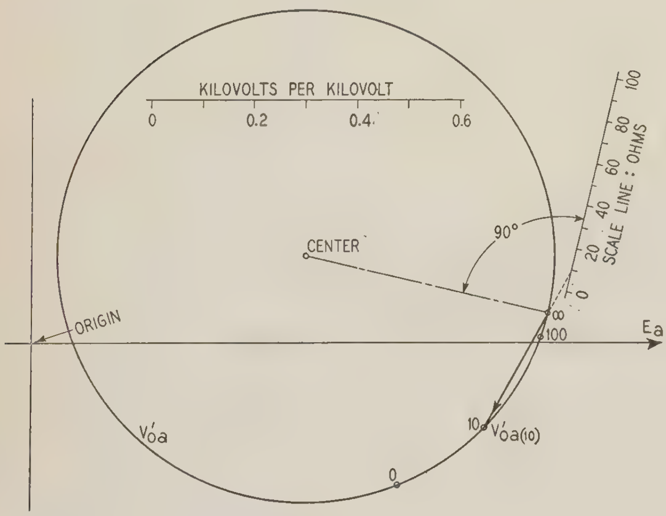


Fig. 11. Locus of voltage across phase a of the source (V_{oa}') of circuit of figure 2 with mutual impedances

$Z_{ab} = j5$ ohms
$Z_{bc} = j10$ ohms
$Z_{ca} = j7$ ohms
$Z_{rs} = Z_{st} = Z_{tr} = j0.2$ ohms

These mutual impedances are shown in the diagram in figure 2.

No mutual impedances will be considered to exist among the load phases because of the nature of the load impedances assumed in this problem. However, if these mutual impedances were present they merely would be added in to form the general constants of the current equations as indicated by equations 32 to 37. The same applies to mutual impedances involving the neutral.

The resistance arm Z_{11} of the load will be considered as the variable self-impedance and the various currents and voltages will be evaluated as a function of R, that is, Z_{11} in terms of unit internal voltage in phase a of the source, which will be considered as the reference vector.

Substituting the circuit constants into the expressions for the general coefficients, equations 32 to 37, and then substituting these coefficients into equations 38 to 42 the following linear fractional transformations are obtained for the current equations:

$$I_a' = \frac{34{,}200\angle 9.9^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (44)$$

$$I_b' = \frac{3{,}983\angle 162.5^\circ + R \times 169.8\angle 167.2^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (45)$$

$$I_c' = \frac{3{,}328\angle -97.3^\circ + R \times 166.8\angle -164.5^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (46)$$

Evaluating the currents (in amperes per kilovolt) for $R = 0$, 10, and ∞,

	$R = 0$	$R = 10$	$R = \infty$
I_a'	$85.96\angle -24.7^\circ$	$49.87\angle -12.7^\circ$	0
I_b'	$10.01\angle 127.9^\circ$	$8.278\angle 141.3^\circ$	$5.516\angle 160.1^\circ$
I_c'	$8.364\angle -131.9^\circ$	$6.212\angle -141.1^\circ$	$5.417\angle -171.6^\circ$

The locus of I_a' is plotted in figure 10. Since no mutuals are present in the load phases, self-impedance drops across the load phases suffice to give the phase voltages at the load. For instance, the voltage V_{01} across phase 1 is I_aZ_{11} or

$$V_{01}' = \frac{R \times 34{,}200\angle 9.9^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ volts per volt} \quad (47)$$

The 3 points necessary to establish the locus of V_{01}' may be obtained by multiplying the values of I_a' in the preceding tabulation by corresponding values of R.

As an example of a voltage involving mutual impedances, the voltage across phase a of the source will be determined. For this purpose V_{oa} may be written

$$V_{oa} = E_1 - I_aZ_{aa} - I_bZ_{ba} - I_cZ_{ca} \quad (48)$$

Substituting the specific values of currents obtained for $R = 0$, 10, and ∞ ohms, the phase voltage becomes

when $R = 0$ $\quad V_{oa}' = 0.7655\angle -21.0^\circ$ volts per volt
when $R = 10$ $\quad V_{oa}' = 0.8953\angle -10.5^\circ$ volts per volt
when $R = \infty$ $\quad V_{oa}' = 1.006\angle 3.6^\circ$ volts per volt

The locus of V_{oa}' is drawn in figure 11.

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Analysis of Rectifier Filter Circuits

The analysis of wave forms in circuits containing rectifiers is in reality a study of transient conditions which repeat cyclically. This paper presents a method of solution for such circuits by means of Fourier series, assuming initially a perfect rectifier with sinusoidal applied voltage. It shows, for cases in which the rectifier conducts current continuously, that the curve of voltage output from rectifier to d-c load consists of sinusoidal segments, and that the series for this voltage can be used, term by term, to find the current series. In some circuits the rectifier conducts current for only a portion of the cycle; in such cases the voltage curve consists of sinusoidal parts joined by sections of other forms. Wave forms are found by computation for several typical circuits, and verified by oscillograms.

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RECTIFIERS of various kinds are finding continually wider application in all branches of electrical work, not only as sources of direct current, but also for other purposes, such as measurement of alternating current by d-c meters, oscillographic recording of mechanical measurements, etc. In many cases it is important to make an analytical study of current and voltage conditions in the circuit, either for the determination of meter readings, or for an analysis of wave forms. The wave forms are determined by the load circuit in some cases, in other cases a filter is interposed between rectifier and load. Analysis of rectifier circuits presents difficulties not encountered in ordinary a-c circuits, due to the changing conduction of the rectifier with reversal of current flow. The wave forms, in general, are composed of sinusoidal parts and transient terms which recur cyclically.

The problem of wave form can be solved, in theory at least, by writing the differential equations of the circuit, solving for the roots, and evaluating the constants to conform with the boundary conditions. The solution for the roots and for the constants becomes exceedingly difficult if the circuit is at all involved. In addition, the results are obtained in a form which is difficult to interpret for many purposes.

The object of this paper is to present a method of analysis using Fourier series to represent currents and voltages. The use of series is not new, as applications have been made in many cases in the expression of rectifier voltage forms, and to some extent in the solution for currents.[1,2] There does not seem to be, however, a clear understanding of the limitations of the simple voltage series made up of sections of sine loops. On the other hand, the full possibilities have not been realized in the development of a general method. It is felt that the extension of the series method here presented will make the entire idea more useful and broader in application.

Circuit Conditions and Assumptions

In this paper rectifiers will be treated purely as switching devices, or "valves." This point of view applies to power circuits, in contrast with the detectors employed in communication circuits. It will be assumed that departures of the rectifier from pure valve action either are unimportant, or else can be treated with sufficient accuracy by an approximation. The method is accordingly studied in 2 parts, first the assumption is made of a hypothetical "perfect rectifier," then rectifier imperfections are taken into account. The perfect rectifier is defined as one in which the impedance is zero to current flow in one direction, and infinite to flow in the inverse direction.

The rectifiers discussed in this paper are of the single phase, full wave type. This is not a necessary limitation. Extension of the method can be made to other types. The alternating voltage applied to the rectifier and its circuit is assumed to be of pure sinusoidal form.

Wave Forms in Simple Circuits

Full wave rectification is obtained from either circuit of figure 1, where the arrow symbol is used to denote a circuit element having unilateral conducting properties. In (*a*) 2 rectifying elements are used, so that current flows from the transformer center tap to the load, and returns through the 2 rectifiers alternately to the transformer terminal which is negative at the instant. In the bridge, or Graetz, circuit of figure 1(*b*), 4 rectifying elements are used, 2 of which are conducting current and 2 blocking for any half cycle. The 2 circuits give essentially the same load effect, assuming zero transformer impedance. No further distinction will be made between them.

Circuits of various characteristics will be connected in the position marked "load" in figure 1, beginning with the simple cases of pure resistance, resistance and inductance in series, and resistance and capacitance in parallel. Development will then be

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1. For all numbered references, see list at end of paper.

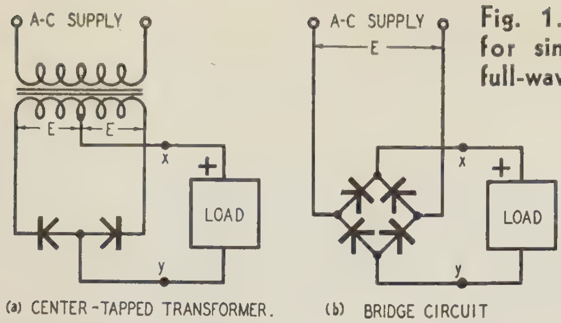


Fig. 1. Circuits for single-phase full-wave rectification

made to care for more complicated circuits. The term "input voltage" used throughout this paper should be understood to mean the voltage measured at the input to the load circuit, that is, between terminals x and y of figures 1.

1. Resistive Load

The supply voltage is assumed to be sinusoidal in form so that the rectified voltage is represented by $e = E_{max} \sin \omega t$ from 0 to π, and by $e = -E_{max} \sin \omega t$ from π to 2π. This voltage may be expressed by the series,[1]

$$e = E_{max}\frac{2}{\pi}\times \left[1 - \frac{2}{3}\cos 2\omega t - \frac{2}{15}\cos 4\omega t - \ldots - \frac{2}{n^2-1}\cos n\omega t\ \ldots\right] \quad (1)$$

The equation for the current i is identical with this in form, with E_{max} replaced by I_{max}. Furthermore, $I_{max} = E_{max} \div R$.

The oscillograms of current and voltage wave forms of figure 2 show agreement with the theoretical shapes. This oscillogram, and others shown later, were taken with the circuit of figure 1(a), using a 60-cycle electromotive force of 230 volts for each half of the transformer secondary. A type 83 tube was employed as the rectifier.

Voltage curves consisting of sinusoidal loops all on the same side of the axis are encountered in many circuits other than the foregoing resistive case. This type of variation will be termed, for convenience, the "sine-loop" voltage.

2. Resistance and Inductance in Series

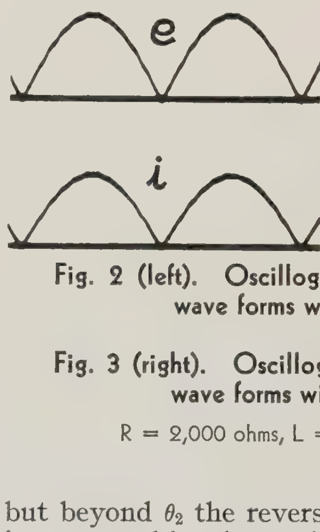
In case the circuit contains inductance, the current does not drop to zero at the end of the half cycle, but has a value at this instant denoted by i_0. The current for the succeeding half cycle must start from this value, as the current cannot be discontinuous in an inductive circuit. If the circuit has been closed long enough so that starting effects are negligible, all half cycles must be identical, so that i_0 is the starting value and the ending value for each half cycle. The form of the current curve may be obtained by using the differential equation for the interval 0 to π, and applying the boundary conditions $i = i_0$ at $\omega t = 0$ and at $\omega t = \pi$. The coefficients of the Fourier series to represent the current may be found by the usual methods of analysis.[3] The resulting series is most easily interpreted if the sine and cosine terms of each harmonic are combined in a single term to give amplitude and phase angle. The series then becomes

$$i = E_{max}\frac{2}{\pi}\left[\frac{1}{R} - \frac{2}{3}\frac{1}{R^2+(2\omega L)^2}\cos\left(2\omega t - \tan^{-1}\frac{2\omega L}{R}\right) - \ldots\ldots - \frac{2}{n^2-1}\frac{1}{R^2+(n\omega L)^2}\cos\left(n\omega t - \tan^{-1}\frac{n\omega L}{R}\right)\ldots\right] \quad (2)$$

Comparison of the current series of equation 2 with the voltage series of equation 1 shows that any term of the current series could have been obtained, in magnitude and in phase, from the corresponding term of the voltage series by dividing the voltage by the impedance of the circuit for that particular frequency. It will be seen later that this convenient method for obtaining the equation of the current can be used in a large class of circuit problems. The oscillogram of figure 3 shows the current form for a series combination of $L = 5$ henrys and $R = 2{,}000$ ohms, at 60 cycles.

3. Resistance and Capacitance in Parallel

The parallel combination of resistance and capacitance is of particular interest in illustrating a type of behavior frequently encountered in rectifier circuits. If, initially, the combination of figure 4(a) is connected to an a-c supply, without a rectifier, the branch currents i_C and i_R have the phase relationship to the voltage shown in figure 4(b). The total current passes through zero at θ_2 where i_C and i_R are equal and opposite. Beyond θ_2 the total current is negative. If the parallel R and C combination is connected as a load to either rectifier circuit of figure 1, the behavior is the same up to the angle θ_2,



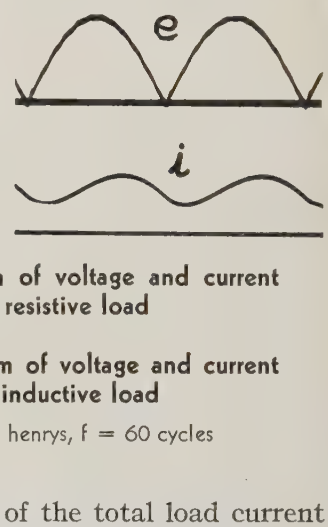


Fig. 2 (left). Oscillogram of voltage and current wave forms with resistive load

Fig. 3 (right). Oscillogram of voltage and current wave forms with inductive load

R = 2,000 ohms, L = 5 henrys, f = 60 cycles

but beyond θ_2 the reversal of the total load current is prevented by the rectifier. The effect, with a perfect rectifier, is as though the switch S were opened at θ_2, disconnecting the circuit from the supply. After θ_2 the condenser discharges through the resistance, giving a simple exponential decay of voltage, represented by the equation

$$e = E_{max}\sin\theta_2\epsilon^{-\frac{1}{CR}t} = E_{max}\sin\theta_2\epsilon^{-\frac{1}{\omega CR}\omega t}$$

where the t and ωt in the exponents are measured from the θ_2 point.

The exponential section continues until a point $\pi + \theta_1$ is reached where the increasing sinusoidal voltage of the next half cycle becomes as great as the voltage across C and R. Conduction is now resumed, following immediately the sinusoidal pattern if the applied a-c voltage retains the pure sine form (negligible voltage drops in the supply system). The combination of sinusoidal and exponential sections is shown in the e and i_R curves of figure 4(c). The condenser current follows a segment of a cosine curve from θ_1 to θ_2, and then is equal and opposite to i_R from θ_2 to $\pi + \theta_1$. The sudden changes of i_C and i_{total} imply, of course, negligible resistance and inductance in the supply system.

The angle θ_2, which marks the transition of the rectifier from the conducting to the nonconducting period, will be referred to as the "cut-out point." It can be found by equating $i_C = \omega C\, E_{max} \cos \omega t$ to the negative of $i_R = (E_{max} \sin \omega t) \div R$, for $\pi t = \theta_2$, giving the result,

$$\theta_2 = \tan^{-1}(-\omega CR) \qquad (3)$$

The angle θ_1, or $\pi + \theta_1$, where conduction begins, will be called the "cut-in point." It is determined by the condition that the exponential voltage after a decay period of $\theta_1 + \pi - \theta_2$ is equaled by the rising sinusoidal voltage. This may be expressed by the equation,

$$E_{max} \sin \theta_2 \epsilon^{-\frac{\theta_1 + \pi - \theta_2}{\omega CR}} = E_{max} \sin \theta_1 \qquad (4)$$

where θ_2 can be regarded as known. Solution for θ_1 is made difficult by its presence in sine and exponential functions. In a numerical case, however, the value of θ_1 can be found either by trial or by graphical means.

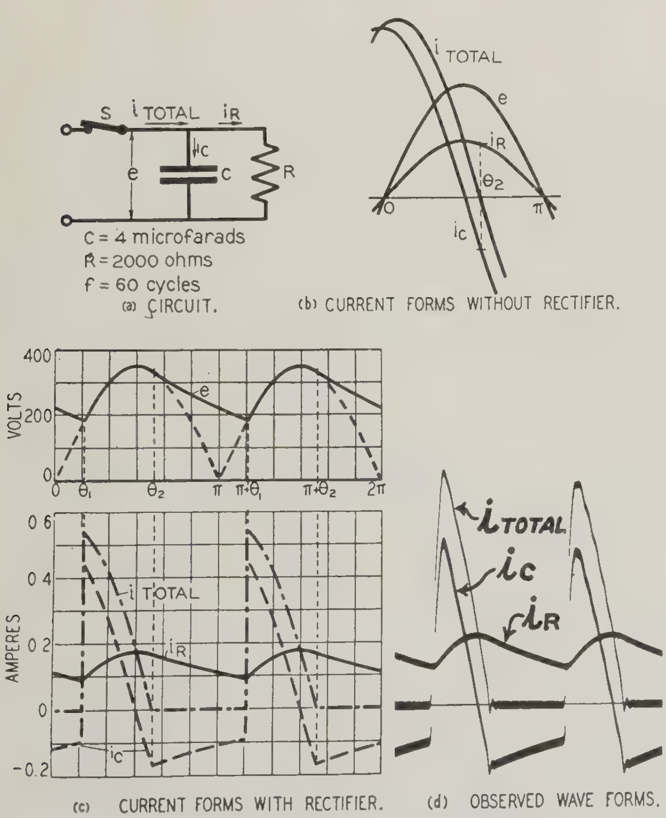
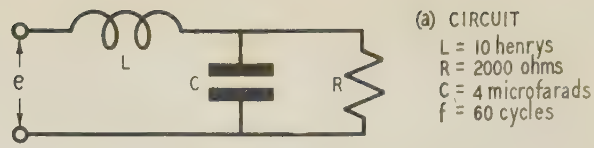


Fig. 4. Voltage and current wave forms, R and C in parallel full-wave rectifier



COMPUTED HARMONIC TERMS

	e	i_L	i_C	i_R		e	i_L	i_C	i_R
					$b_0/2$	225.1	.1125	0	.1125
a_2	0	-.0208	-.0202	-.0006	b_2	-150.1	-.0002	-.0035	+.0033
a_4	0	-.0020	-.0020	—	b_4	-30.0	—	-.0002	+.0002
a_6	0	-.0006	-.0006	—	b_6	-12.9	—	—	—
a_8	0	-.0002	-.0002	—	b_8	-7.1	—	—	—
a_{10}	0	-.0001	-.0001	—	b_{10}	-4.6	—	—	—

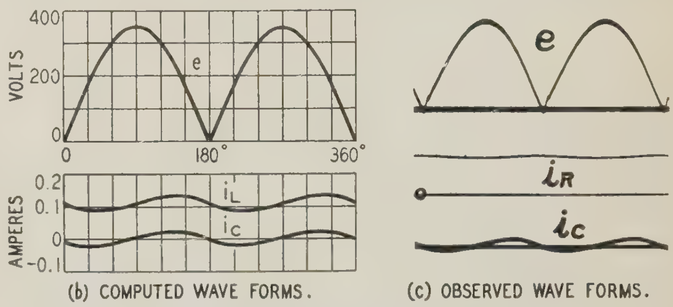


Fig. 5. Wave forms and harmonic terms for a continuous conduction case

It would not be expected that the sine-loop voltage of equation 1 would yield the correct current series in this case, as the actual input voltage follows a different variation, shown by the e curve of figure 4(c). A modified series can be found for this combination of sine and exponential sections by the usual Fourier methods. (Or, see appendixes I and II.) The angles θ_1 and θ_2 and the series coefficients are functions of ωCR, and may be shown by a plot with ωCR as abscissa. Such a graph is not included here, however, due to lack of space.

The experimental curves, shown in the figure 4(d), follow the theoretical forms except for the sudden rise at the cut-in point. The experimental curves at this point necessarily show a finite slope, due to resistance and inductance in the supply lines, and also to the inertia of the oscillograph element. The curve of the voltage e was not included in the oscillogram, as it must of necessity be of the same shape as the current through the resistance.

General Circuit Solution

The first step in the solution of a circuit is the computation of the circuit constants for the frequencies of the harmonics found in the rectified wave, which, for a single-phase full-wave rectifier, are the even multiples of the power line frequency. The circuit constants for each frequency are best expressed as admittances based upon the voltage at the input terminals of the circuit, or, in other words, as the currents which flow in various parts of the circuit

upon the application of one volt of that particular frequency at the input. In addition, the voltage for any part of the circuit, for any harmonic, may be expressed by a multiplier applied to the input voltage.

The circuit of figure 5 will be used to illustrate the method of solution. Table I gives a tabulation of admittances for the total current i_L and for the branch currents l_R and i_C as found by the usual methods of circuit solution by the complex algebra. In this case L was taken as a pure inductance, for simplicity. However, this is not necessary, and except for the small additional labor in computing admittances, the resistances of choke coils can just as well be included. The current terms are found from the voltage by the usual circuit methods. Using the complex notation, with the sine voltage as reference, the current terms are

$$\begin{aligned} i_n = e_nY_n &= (a_n + jb_n)(G_n + jB_n) \\ &= (a_nG_n - b_nB_n) + j(b_nG_n + a_nB_n) \\ &= a_n' + jb_n' \end{aligned} \tag{5}$$

Here a_n and b_n are used to represent the sine and cosine terms, respectively, of the nth harmonic of the voltage series, and a_n' and b_n' the corresponding current terms. The computation can be carried out in a tabular form, as for example, that of table II. The applied voltage has the form of equation 1, with an effective value of 250 volts and a frequency of 60 cycles per second.

The current wave can be plotted by computing ordinates at intervals for the series whose coefficients are given in table II. A form for this purpose is shown in table III, in which ordinates are found at 10 degree intervals. The figures in the "multiplier" column are the appropriate sine and cosine functions of the multiple angles, and are parts of the form sheet to be used in all such computations. It is possible that a more compact arrangement could be devised, but this has at least the merit of showing clearly the processes involved. The computation is less extensive than would appear at first glance, as each a or b term is multiplied by only 4 factors. Symmetry of some form exists about 0 degrees (or 180 degrees) and 90 degrees for all harmonics, so that, for any a or b, the entries in the table are found to be the same, except for sign, at 10, 80, 100 and 170 degrees, and similarly for other angles.

The solution obtained in the foregoing manner is the correct solution, provided that, as in this case, the total current does not show a negative value at any point. The currents and voltages can be computed for any desired part of the circuit from the input voltage and the circuit constants as in table II. The current wave forms are shown in figure 5 for i_L and i_C. The plot of i_R is not given, as it would be nearly a straight line. The harmonic content of i_R, however, is shown in the tabulation beside the curves, and indicates a very rapid decrease in the magnitude of the higher frequency terms.

Table I—Admittances for the Circuit of Figure 5

Harmonic	f	Y_L		Y_R		Y_C	
		G_L	B_L	G_R	B_R	G_C	B_C
		$\times 10^{-6}$		$\times 10^{-6}$		$\times 10^{-6}$	
0 (DC)	0	500	–	500	–	–	–
2	120	+1.027	−138.55	−22.33	−3.87	+23.36	−134.68
4	240	+0.062	−67.05	−5.52	−0.46	+5.58	−66.58
6	360	+0.012	−44.43	−2.45	−0.14	+2.46	−44.29
8	480	+0.003	−33.25	−1.38	−0.06	+1.38	−33.19
10	600	+0.002	−26.57	−0.88	−0.03	+0.88	−26.54

Table II—Computation of Current Series for i_L, Figure 5

Term	Input Voltage	Y_L			i_L amperes
		G $\times 10^{-6}$	bG	aB	$\times 10^{-6}$
$b_0/2$	225.08	+5.00	+112540	–	+112540
b_2	−150.05	+1.03	−155	0	−155
b_4	−30.01	+.06	−2	0	−2
b_6	−12.86	0	0	0	0
b_8	−7.15	0	0	0	0
b_{10}	−4.55	0	0	0	0
		B	aG	−bB	
a_2	0	138.55	0	−20789	−20789
a_4	0	−67.05	0	−2012	−2012
a_6	0	−44.43	0	−571	−571
a_8	0	−33.25	0	−238	−238
a_{10}	0	−26.57	0	−121	−121

Occurrence of negative values in the total current is evidence that the rectifier is actually not passing current continuously, that is, cut-off is taking place. In this event the circuit must be given further study, and the proper modification made in the input voltage.

Circuits Causing Cut-Off

The occurrence of negative values in the total current drawn by the load is evidence that the assumed input voltage is not of the proper form. The rectifier prevents reverse current flow, and in so doing, disconnects the circuit from the supply for a time. During the cut-off period the load voltage follows a different pattern than the sinusoidal supply voltage. The series method can still be used in such cases if the input voltage equation is modified to express correctly the voltage during the cut-off period. For complicated circuits, the voltage is not known in advance, but it can be approached by a system of approximations. It is difficult to give definite rules that will give the easiest approach in all cases. The judgment and ingenuity of the operator are valuable components of the process. It is possible, however, to indicate general methods of procedure.

Cut-off is caused by the energy storage of a condenser in the circuit. The condenser may be directly across the input terminals, or there may be some series impedance between the input terminals and the condenser. The first type of circuit corresponds to what is termed in filter parlance a "condenser-input" filter. The "choke input" filter is an example of the second type. Cut-off may occur with either type, depending upon the circuit constants. The 2 types represent a natural division in circuit study, as different methods apply in the 2 cases. Examples

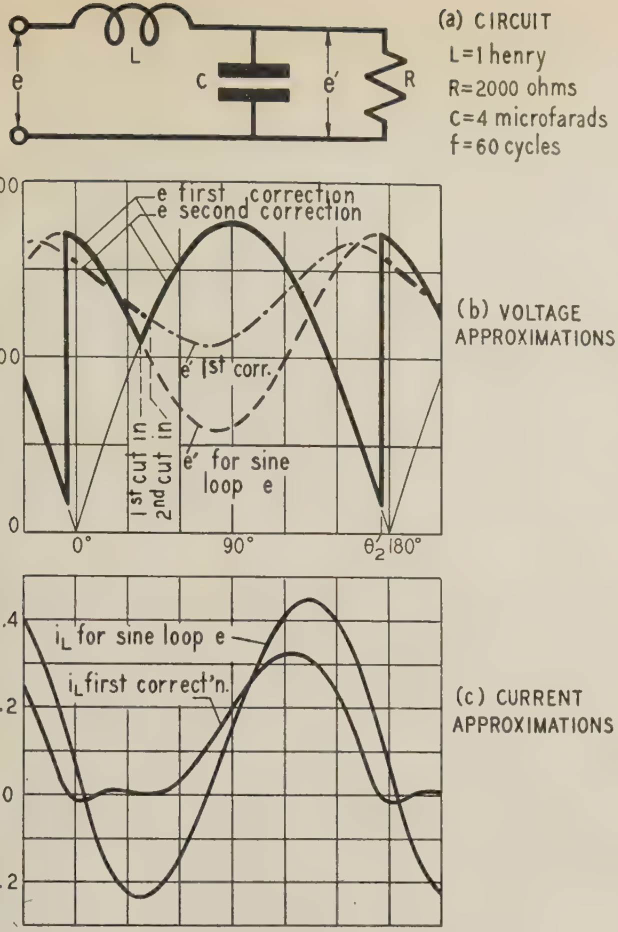


Fig. 6. First approximation and corrections for a cut-off case, series impedance input

will be given to illustrate the procedure with the 2 types.

A—Series Impedance Input

The input voltage is sinusoidal during the conducting period. While the input current is zero, there is, of course, no voltage drop across the impedance at the input, and consequently the voltage measured at the input is the same as the voltage across the condenser nearest the input. The general plan of procedure is to find the cut-out and cut-in points, and to make up the input voltage of a sinusoidal section during conduction and a section equal to the condenser voltage during cut-off. The desired quantities may be found by successive approximations, approaching as closely as desired to the true values.

The circuit arrangement of figure 5 will be used, with the exception that L is reduced to one henry, in order to produce cut-off. A trial value of current, found from the sine loop voltage by the methods described previously, shows that cut-off does occur, as the total current is negative from 5 to 75 degrees, as shown in the plot of figure 6. The voltage e' (See figure 6*a*) computed on the assumption of sine loop input voltage, is plotted in the same figure. The intersection of e' with the sine voltage at 38 degrees gives a first approximation to the cut-in angle θ_1, as the intersection has the same general significance as in the *R-C* circuit of figure 4. The cut-out angle θ_2 is not determined definitely, but can be judged to be somewhat earlier than the 185 degree(or 5 degree) point where i_L goes negative, due to the fact that i_L in the new trial is to become positive at 38 degrees, instead of the 75 degrees referred to above. Accordingly, a value of 175 degrees is used as a first approximation.

A first correction to the voltage e at the input terminals can be obtained by following the curve of e' (for sine loop input) during the cut-off period, that is, from approximately 175 to 38 degrees (or 180 + 38 degrees), and by following the sine curve during the conduction portion of the cycle. This variation shown by the heavy solid line of figure 6(*b*), can be represented by a series. The coefficients needed for the sinusoidal section are obtained from the formulas of appendix II. The coefficients required to make the new series follow the old e' during the cut-out period may be found from appendix IV. Addition of the coefficients of corresponding terms for the 2 sections gives the new voltage equation. This voltage cannot be strictly correct, as the e' used in finding it was only approximate, but it is at least much closer to the true value than was the original sine loop voltage.

The curve of i_L from the revised voltage series, plotted in figure 6(*c*), shows values which are fairly close to zero during the cut-off period. If greater accuracy is desired, the correction process can be carried out again, using the e' from the first correction voltage as the e during cut-out for the second correction. A new value of θ_1 is taken from the intersection of the revised e' curve with the sine curve at approximately 43 degrees. A new value of the cut-out point, at θ_2 = 174 degrees is taken to eliminate the small negative value of current found in the first correction. The results of the sine loop approximation and the first and second corrections of i_L and e' are shown in table IV. The difference between the first and second corrections are sufficiently small to indicate that additional corrections would make only

Table III—Ordinates for i_L Curve, Figure 5

		0°		10°		20°		30°		40°		50°	
		Mult	Prod	Mult.	Prod	Mult	Prod	Mult.	Prod	Mult	Prod	Mult	Prod
a_2	−2079	00	0	3420	−711	6428	−1336	8660	−1800	9848	−2047	9848	−2047
b_2	−16	1 00	−16	9397	−15	7660	−12	5000	−8	1736	−3	−1736	+ +3
a_4	−201	00	0	6428	−129	.9848	−198	8660	−174	3420	−69	−3420	+69
b_4	0	1 00	—	7660	—	1736	—	−500	—	−9397	—	−9397	—
a_6	−57	00	0	8660	−49	8660	−49	00	0	−8660	+49	−8660	+49
b_6	0	1 00	—	5000	—	−5000	—	−1 00	—	−5000	—	5000	—
a_8	−24	00	0	9848	−24	3420	−8	−8660	+21	−6428	+15	6428	−15
b_8	0	1 00	—	1736	—	−9397	—	−5000	—	.7660	—	7660	—
a_{10}	−12	.00	0	9848	−12	−.3420	+4	−.8660	+10	.6428	−8	.6428	−8
b_{10}	0	1 00	—	−.1736	—	−.9397	—	5000	—	.7660	—	−7660	—
Amperes ($\times 10^{-5}$)			11238		10314		9655		9303		9191		9305

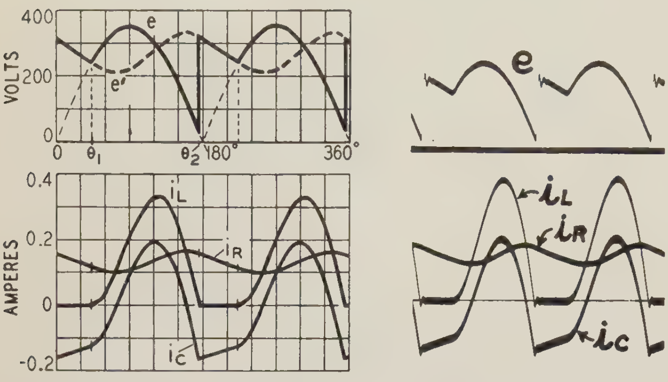
		60°		70°		80°		90°		100°		110°	
		Mult	Prod	Mult	Prod	Mult.	Prod	Mult	Prod	Mult	Prod	Mult	Prod.
a_2	−2079	8660	−1800	6428	−1336	.3420	−711	00	0	−3420	+711	−.6428	+1336
b_2	−16	−5000	+8	−7660	+12	−.9397	+15	−1.00	+16	−9397	+15	−7660	+12
a_4	−201	−8660	+174	−9848	+198	−6428	+129	00	0	6428	−129	9848	−198
b_4	0	−5000	—	1736	—	7660	—	1.00	—	7660	—	1736	—
a_6	−57	00	0	8660	−49	8660	−49	00	0	−8660	+49	−8660	+49
b_6	0	1 00	—	5000	—	−5000	—	−1.00	—	−5000	—	5000	—
a_8	−24	8660	−21	−3420	+8	−9848	+24	00	0	9848	−24	3420	−8
b_8	0	−5000	—	−9397	—	1736	—	1 00	—	1736	—	−9397	—
a_{10}	−12	−.8660	+10	−.3420	+4	9848	−.2	.00	0	−9848	+12	.3420	−4
b_{10}	0	−5000	—	9397	—	.1736	—	−1.00	—	1736	—	9397	—
Amperes ($\times 10^{-5}$)			9625		10091		10650		H270		11888		12441

		120°		130°		140°		150°		160°		170°	
		Mult	Prod.	Mult	Prod	Mult	Prod.	Mult.	Prod.	Mult	Prod.	Mult	Prod.
a_2	−2079	−8660	+1800	−9848	+2047	−.9848	+2047	−.8660	+1800	−.6428	+1336	−.3420	+711
b_2	−16	5000	+8	−.1736	+3	1736	−3	.5000	−8	.7660	−12	.9397	−15
a_4	−201	6660	−174	3420	−69	−.3420	+69	−.8660	+174	−.9848	+198	−6428	+129
b_4	0	−5000	—	−.9397	—	−.9397	—	−5000	—	.1736	—	7660	—
a_6	−57	00	0	8660	−49	.8660	−49	.00	0	−8660	+49	−8660	+49
b_6	0	1 00	—	5000	—	−5000	—	−1 00	—	−5000	—	.5000	—
a_8	−24	−8660	+21	−6428	+15	6428	−15	8660	−21	−3420	+8	−.9848	+24
b_8	0	−5000	—	7660	—	.7660	—	−5000	—	−9397	—	.1736	—
a_{10}	−12	8660	−10	−.6428	+8	−6428	+8	8660	−10	.3420	−4	−.9848	+12
b_{10}	0	−.5000	—	−7660	—	.7660	—	.5000	—	−.9397	—	−.1736	—
Amperes ($\times 10^{-5}$)			12899		13209		13311		13189		12829		12164

Multiplier = 10^{-5} Constant term = $b_0/2$, = 11254 Add to all columns.

COMPUTED HARMONIC TERMS.

	e	i_L	i_C	i_R		e	i_L	i_C	i_R
					$b_0/2$	+270.3	+.1351	0	+.1351
a_2	+29.0	-.1557	-.1376	-.0181	b_2	-71.8	-.0866	-.1094	+.0228
a_4	+40.3	+.0162	+.0186	-.0023	b_4	+21.4	-.0300	-.0283	-.0015
a_6	+32.3	+.0072	+.0080	-.0008	b_6	+15.5	-.0150	-.0145	-.0004
a_8	+17.6	+.0040	+.0043	-.0002	b_8	+11.8	-.0060	-.0058	-.0002
a_{10}	+8.1	+.0038	+.0039	-.0001	b_{10}	+14.2	-.0022	-.0021	-.0001



(a) COMPUTED WAVE FORMS. (b) OBSERVED WAVE FORMS.

Fig. 7. Wave forms and harmonic terms for a cut-off case, series impedance input. Circuit of figure 6

minor changes. Figure 7 gives the complete wave form and harmonic terms for the corrected input voltage. It is interesting to note the form of the voltage, with its change from the sine to the e' curve when conduction ceases. Also, the e', i_R and i_C curves are seen to have exponential sections during the cut-off period. The oscillogram of figure 7(b) was taken for a circuit having quite closely the constants of the computed case.

Advantage could have been taken in this problem of the fact that the voltage e' is exponential during the cut-off period. With θ_1 and θ_2 determined approximately, a combined sinusoidal and exponential series could have been obtained by appendixes I and II. The computation would have been somewhat simpler than for the method above. The general method was illustrated, however, as it can be used with complicated circuits where nothing is known in advance of the form of the curve during cut-off. Multisection filters, for example, fall in this class.

B—Condenser Input

A condenser input circuit does not produce cut-off in all cases. However, for the values of resistance, inductance, and capacitance used in practical filter circuits, cut-off does occur. It can be stated, moreover, that a condenser across the input is of no value in smoothing the output current unless it is of sufficient capacity to cause cut-off, since continuous conduction means that the input voltage is of the sine loop form, of definite harmonic content (see equation 1). The input voltage is made smoother than this by the effect of cut-off, as shown for a simple case by the e' curve of figure 4(c). The effects in a circuit more representative of filter design are shown by the

Table IV—Successive Approximations, Circuit of Figure 6

Term	Sine Loop Voltage		First Correction		Second Correction	
	e volts	i_L amperes	e volts	i_L amperes	e volts	i_L amperes
$b_0/2$	225.08	.1125	270.71	.1354	270.28	.1351
b_2	-150.05	-.0425	-69.00	-.0838	-71.77	-.0866
b_4	-30.01	-.0002	+26.84	-.0315	+21.38	-.0299
b_6	-12.86	-	+19.62	-.0183	+15.46	-.0150
b_8	-7.15	-	+11.31	-.0090	+11.78	-.0060
b_{10}	-4.55	-	+10.86	-.0037	+14.17	-.0022
a_2	0	-.3427	+28.16	-.1496	+29.00	-.1557
a_4	0	-.0223	+42.59	+.0203	+40.32	+.0162
a_6	0	-.0060	+39.48	+.0092	+32.30	+.0072
a_8	0	-.0024	+26.26	+.0039	+17.63	+.0040
a_{10}	0	-.0012	+13.73	+.0029	+8.11	+.0038
θ_1			38°		43°	
θ_2			175°		174°	

arrangement of figure 8(a), where the constants are so chosen that cut-off does occur.

The intial procedure for a condenser input circuit is similar to the general method described previously, except that the admittance constants should be computed for the total current exclusive of the condenser at the input. The current to the input condenser is determined in a special manner, since it possesses discontinuities which cause difficulties in accurate series representation. The peculiarities of the condenser behavior are, however, used to advantage in the following approximation method of solution. The procedure in this problem can be outlined as follows:

1. Find i_L due to an approximately correct input voltage. The sine loop voltage of equation 1 could be used as a first approximation to the input voltage. However, considerable labor can be saved and the approximation process shortened, if an initial voltage series is devised which is closer to the true form. It is known that energy storage in the input condenser has the effect of bridging over the "valleys" between loops of the sine voltage. Accordingly, a voltage series selected from suitable values of an R-C circuit, which has the same general smoothing effect (see figure 4), is a better first guess than the sine loop voltage.

2. Estimate the cut-out angle θ_2. This can be done by finding the point where i_C has a negative value, on the cosine curve, equal and opposite to i_L.

3. Estimate the cut-in angle θ_1. During cut-off period, i_L is drawn entirely from condenser C_1, and hence is a measure of the decrease of the voltage across it. Beginning at θ_2, find the discharge of C_1 up to 2 points such as, in this case, 25 degrees and 35 degrees. It is then possible to interpolate between the points and find the angle at which the decreasing condenser voltage is equaled by the increasing sinusoidal voltage.

4. Find the series for the current i_{C1}. It would be undesirable to find i_{C1} from the approximate input voltage, as any discrepancies in the voltage form would be magnified in the condenser current. A more accurate method is to find i_{C1} by sections, since it is known to follow a cosine curve during the conduction period, and to be equal and opposite to i_L during the cut-off period. The formulas of appendix III serve for the coefficients of the cosine section, and those of appendix IV for the cut-off section. Addition of coefficients, term by term, for the 2 sections gives the complete i_C series.

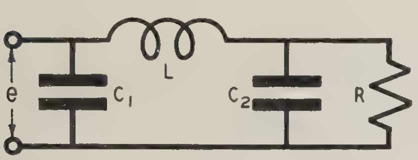
5. Obtain a corrected input voltage series. The series for i_{C1} is correct for the conduction period, and approximately correct for the cut-off period. Multiplication of each term of the series for i_{C1} by the impedance of C_1 for the corresponding frequency yields a new voltage series which is more accurate than the original approximation. The currents for various branches of the circuit can now be computed, and new values found for θ_1 and θ_2. In case it seems desirable, the correc-

ion process can be carried through a second time. The table of computed terms of figure 8 shows the results of the first correction, which seemed sufficiently accurate, as the changes from the original trial values were relatively small.

It is interesting to compare filtering effects in figure 5 and figure 8, as the circuits are the same except for the addition of the condenser at the input. The input condenser is seen to cause a reduction of harmonic content in all parts of the circuit, and an increase in the d-c component. Both of these effects would be anticipated from the changed form of the input voltage. There is another difference, however, in that the total current drawn through the rectifier is fairly uniform in the choke input case, but is intermittent and has high peaks with the condenser input. The method presented above is useful in the analysis of other filter arrangements, but space does not permit fuller discussion.

A-C Line Current

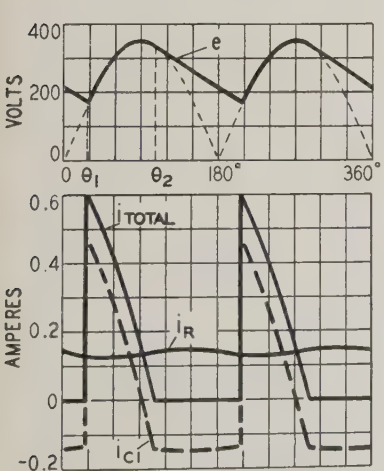
The harmonics of the current in the a-c line wires leading to the rectifier can be found from the harmonics in the rectified current. The line current for the perfect rectifier is similar to the total rectified current, except that the direction is reversed in alternate half cycles. The formulas for finding a-c line harmonics from the rectified current harmonics are easily derived. For the single phase full wave rectifier the a-c line current contains odd harmonics, only.



(a) CIRCUIT
L=10 henrys
R= 2000 ohms
C1, C2=4 microfarads
f = 60 cycles

COMPUTED HARMONIC TERMS

	e	i_L	i_{C1}	i_R		e	i_L	i_{C1}	i_R
					$b_0/2$	+276.2	+.1381	—	+.1381
a_2	−24.8	−.0102	+.2226	+.0003	b_2	−73.8	+.0034	−.0749	+.0017
a_4	−17.7	+.0006	−.0500	+.0001	b_4	+8.3	+.0012	−.1070	—
a_6	−1.5	+.0003	−.0547	—	b_6	+6.1	—	−.0131	—
a_8	+3.2	—	−.0370	—	b_8	+3.1	—	+.0381	—
a_{10}	+2.3	—	+.0118	—	b_{10}	−0.8	—	+.0342	—



(b) COMPUTED WAVE FORMS.

Fig. 8. Wave forms and harmonic terms for a cut-off case, condenser input

Half-Wave Rectifiers

Half-wave rectifier circuits can be solved by the series method, but the difficulty is somewhat inincreased, due to the fact that cut-off occurs, in effect, with all types of load. A series can be written[1] for a voltage which follows the sine form from 0 to π, and which is zero from π to 2π, but this is the correct input voltage only in the very special case of a purely resistive load. For all other cases the input voltage must be modified to suit the circuit. This point is worthy of note, as cases are found in the literature of the application of this so-called half-wave voltage equation to circuits to which it does not properly apply.

Rectifier Imperfections

For some purposes, and in some circuits, the solution on the basis of the hypothetical perfect rectifier is sufficiently accurate. In other cases it is desirable to make at least an approximate correction for the departures of the rectifier from perfect action. The method to be employed in the correction depends upon the type of rectifier used. In the case of a vacuum tube rectifier, if the load voltage is large compared with the tube drop, it may be possible to ignore curvature of the tube characteristic and replace the tube by a constant resistance for the conducting direction. The inverse resistance would still be considered infinite.

For a gaseous conduction rectifier, such as a mercury vapor tube, a good approximation is made by the assumption of a constant tube drop for the conducting direction. This is easily taken into account by the series method, by subtracting the tube drop from the constant term of the voltage series.

The inverse conduction cannot be neglected in the case of contact rectifiers, such as the copper oxide, when high accuracy is desired. Huss has shown[5] that for ordinary power frequencies the copper oxide rectifier can be replaced by 2 resistances, a low resistance D for the conducting direction, and a higher value S for the inverse direction. Under these conditions, for continuous conduction in a full-wave

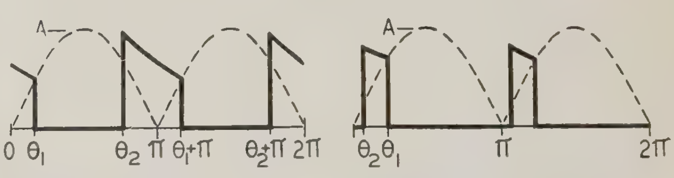


Fig. 9. Curve consisting of exponential sections

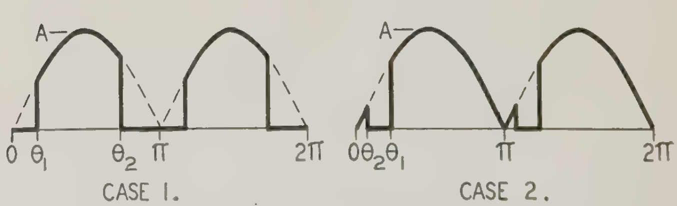


Fig. 10. Curve consisting of sine sections

bridge circuit, the rectified current can be found in terms of the perfect rectifier if a resistance $DS \div (D + S)$ be placed in series with the load, and if the applied voltage be reduced by the factor $(S - D) \div (D + S)$.

Appendix I—Series for Exponential Sections

The series coefficients needed to represent the exponential curve within the limits θ_2 to $\theta_1 + \pi$, and zero elsewhere, as shown in figure 9, are given by the following expressions. The exponential curve is of the form $y = \text{constant}\cdot\epsilon^{-k\theta}$. Cases 1 and 2 differ only in the expression for α.

Even values, only, for m
Multiply all terms by A/π

$$a_m = \frac{2 \sin \theta_1}{k^2 + m^2} \left\{ \epsilon^{k\alpha}(k \sin m\theta_2 + m \cos m\theta_2) - (k \sin m\theta_1 + m \cos m\theta_1) \right\}$$

$$b_m = \frac{2 \sin \theta_1}{k^2 + m^2} \left\{ \epsilon^{k\alpha}(k \cos m\theta_2 - m \sin m\theta_2) - (k \cos m\theta_1 - m \sin m\theta_1) \right\}$$

$$\frac{b_0}{2} = \frac{\sin \theta_1}{k} (\epsilon^{k\alpha} - 1)$$

The multiplying constant is given in terms of the magnitude of the sine curve which intersects the exponential curve at θ_1, to conform with the general usage in this paper. However, other applications can be made by noting that the factor $A \sin \theta_1$ is the ordinate at θ_1.

Appendix II—Series for Sections of a Sine Curve

The series coefficients needed to represent the sine curve between the limits θ_1 and θ_2, and zero elsewhere, as shown by figure 10, are given by the following expressions.

Case 1. Omit terms in brackets
Case 2. Use the complete expression
Even values, only, for m
Multiply all terms by A/π

$$a_m = \frac{\sin(m-1)\theta_2 - \sin(m-1)\theta_1}{m-1} - \frac{\sin(m+1)\theta_2 - \sin(m+1)\theta_1}{m+1}$$

$$b_m = \frac{\cos(m-1)\theta_2 - \cos(m-1)\theta_1}{m-1} - \frac{\cos(m+1)\theta_2 - \cos(m+1)\theta_1}{m+1} - \left[\frac{4}{m^2 - 1}\right]$$

$$\frac{b_0}{2} = \cos \theta_1 - \cos \theta_2 + [2]$$

Note that all terms contain sine and cosine functions of the general form $(\sin k\theta_2 - \sin k\theta_1)/k$, k being odd. This makes possible the computation of a and b values for all harmonics up to, say, the 10th in a compact tabular form.

Appendix III—Series for Cosine Sections

The series coefficients needed to represent the cosine curve within the limits θ_1 to θ_2, and zero elsewhere, as shown in figure 11, are given by the following expressions.

Even values, only, for m
Multiply all terms by A/π

$$a_m = -\frac{\cos(m-1)\theta_2 - \cos(m-1)\theta_1}{m-1} - \frac{\cos(m+1)\theta_2 - \cos(m+1)\theta_1}{m+1}$$

$$b_m = \frac{\sin(m-1)\theta_2 - \sin(m-1)\theta_1}{m-1} + \frac{\sin(m+1)\theta_2 - \sin(m+1)\theta_1}{m+1}$$

$$\frac{b_0}{2} = \sin \theta_2 - \sin \theta_1$$

Fig. 11. Curve consisting of cosine sections

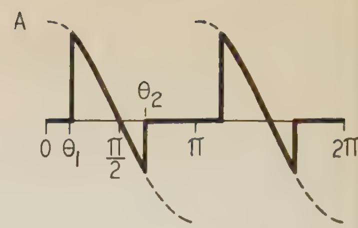


Fig. 12. New series derived from old series

Appendix IV—Series for Sections of Another Series Curve

A series can be found whose curve follows an old series between the limits θ_2 and θ_1, but is zero elsewhere, by means of the following expressions. Small letters are used to represent coefficients of the old series, and capital letters the new series.

Even values, only, for n and m

$$A_m = -2\frac{b_0}{2}\frac{\cos m\theta_1 - \cos m\theta_2}{\pi m} +$$
$$a_m\left[\frac{\theta_1 - \theta_2}{\pi} - \frac{\sin 2m\theta_1 - \sin 2m\theta_2}{\pi 2m}\right] - b_m \frac{\cos 2m\theta_1 - \cos 2m\theta_2}{\pi 2m} +$$
$$\sum_{n \neq m} a_n \left[\frac{\sin(m-n)\theta_1 - \sin(m-n)\theta_2}{\pi(m-n)} - \frac{\sin(m+n)\theta_1 - \sin(m+n)\theta_2}{\pi(m+n)}\right] +$$
$$\sum_{n \neq m} b_n \left[-\frac{\cos(m-n)\theta_1 - \cos(m-n)\theta_2}{\pi(m-n)} - \frac{\cos(m+n)\theta_1 - \cos(m+n)\theta_2}{\pi(m+n)}\right]$$

$$B_m = 2\frac{b_0}{2}\frac{\sin m\theta_1 - \sin m\theta_2}{\pi m} +$$
$$b_m\left[\frac{\theta_1 - \theta_2}{\pi} + \frac{\sin 2m\theta_1 - \sin 2m\theta_2}{\pi 2m}\right] - a_m \frac{\cos 2m\theta_1 - \cos 2m\theta_2}{\pi 2m} +$$
$$\sum_{n \neq m} b_n \left[\frac{\sin(m-n)\theta_1 - \sin(m-n)\theta_2}{\pi(m-n)} + \frac{\sin(m+n)\theta_1 - \sin(m+n)\theta_2}{\pi(m+n)}\right] +$$
$$\sum_{n \neq m} a_n \left[\frac{\cos(m-n)\theta_1 - \cos(m-n)\theta_2}{\pi(m-n)} - \frac{\cos(m+n)\theta_1 - \cos(m+n)\theta_2}{\pi(m+n)}\right]$$

$$\frac{B_0}{2} = \frac{b_0}{2}\frac{\theta_1 - \theta_2}{\pi} +$$
$$\sum_{n=2,4,\ldots} b_n \frac{\sin n\theta_1 - \sin n\theta_2}{\pi n} - \sum_{n=2,4,\ldots} a_n \frac{\cos n\theta_1 - \cos n\theta_2}{\pi n}$$

It will be noted that all terms consist of sine or cosine differences of the general form $(\sin k\theta_1 - \sin k\theta_2)/\pi k$, where k is an even integer. These factors can be computed easily in a tabular form. If sine and cosine factors are tabulated for k up to twice the highest harmonic being used in the circuit computations, all factors entering into the computations will be at hand. The grouping of the factors for the finding of the various A_m and B_m terms can be facilitated greatly by the use of a form sheet, or a stencil system.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 19 pages appear discussions of papers presented at the distribution & transmission and insulation & protection sessions of the South West District meeting, Oklahoma City, Okla., April 24–26, 1935, and at the instruments and measurements, power generation, and selected subjects sessions of the 1935 A.I.E.E. summer convention, Ithaca, N. Y., June 24–28. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Recommended Transformer Standards

Authors' closing discussion of a paper published in the December 1934 issue, pages 1594–7, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 22, 1935, and other discussion was published in the July 1935 issue, pages 770–1, and in the August 1935 issue, pages 887–8.

J. E. Clem: I. W. Gross, in his discussion, raises some very interesting points. Whether or not the transformer design levels proposed by the transformer subcommittee (and at present in use) correspond to those which may result from the recommendations of the joint N.E.M.A.-E.E.I. co-ordination committee is not so important as it might at first seem. The levels given in the paper have developed from experience and have been in use for some time. It should be recognized as necessary that standards be available for use until the joint co-ordination committee completes its labors. If the proposals of that committee require different design levels than at present in use and the proposals are accepted, it should be an easy matter to make whatever changes are required.

It is a reasonable point to raise that the transformer might not be the logical starting point to set up a co-ordination scheme. However, the transformer subcommittee saw the need for some action in regard to transformers some time ago and began the study of the problem as it affected transformers. In reality the proper point for the start of the co-ordination scheme is the protection level. If a protection level were to be set up the design level of equipment could readily be agreed upon.

The 2 years of experience which has been had with the impulse test code have shown that factory impulse tests are practical. Two years is probably too short a time to demonstrate whether or not the right magnitude of impulse test has been selected.

Another point raised by Gross is in reference to the polarity of the test wave. The gap spacings were selected to give insulation strengths about the same as experience had indicated to be generally satisfactory. The selection of gap spacings was made on the basis of the positive wave because flashover data for this wave were much more complete than for the negative wave. If the negative had been used, it is very likely that shorter gap spacings would have resulted. If the negative wave should be used now either shorter gap spacings or more insulation (with increased costs) would be required. It seems that the test using the positive wave should be satisfactory because considerable data is now available for correlating tests made with the positive wave with tests made with the negative wave.

A co-ordination gap, as listed in table I of the paper, may be considered as the gap which establishes the required insulation level for any particular rated circuit voltage. The work of the joint N.E.M.A.-E.E.I. co-ordination committee should yield results which will replace the insulation levels indicated by these gap spacings.

The gap was used to establish insulation levels because of the apparent discrepancy in the impulse flashover data emanating from the various laboratories. It was felt that if the impulse strengths were stated in terms of a gap spacing and tested with a specified wave by gap flashover, the test would be the same regardless of what kilovolt value might be reported. Unfortunately the use of co-ordination gaps was considered by some as affording protection and this has led to considerable confusion. It is hoped that kilovolt values will ultimately be used.

Gross seems to have misinterpreted the information given in table III. Inasmuch as the impulse test is made by flashing over the bushing, it seems obvious that the transformer winding should be stronger than the bushing for the test conditions.

Minimum flashover voltages for transformer bushings were set up by the transformer subcommittee sometime ago as 15 per cent above the flashover of the co-ordination gap. This automatically places the required bushing flashover 5 per cent above the test gap. This standard flashover level is substantially the same as it has been in the past for the circuit voltages at the upper end of the range but becomes increasingly lower as the other end of the range is approached. It is expected that distribution transformer bushings will conform to this standard flashover level, but that power transformers will retain their present bushings, which have a flashover in excess of this level.

Some of C. M. Foust's difficulties, especially those covered by his paragraphs numbers 1 and 3, arise from the fact that the present paper did not copy completely the original impulse test code. Reference to the original test code would clear up all the questions outlined by him. ("Progress Report on Impulse Testing of Commercial Transformers," Montsinger and Vogel. A.I.E.E. TRANS., volume 52, 1933, pages 409–10.)

The question as to whether or not one terminal of the transformer should be grounded during test has not been covered in the test code, but it seems desirable that this be done. This question will be taken up by the transformer subcommittee.

H. V. Putman: For a period of years an effort has been made to establish more rational insulation tests for distribution transformers—tests that would not handicap the design or increase the cost, but that would be of some value as a check in determining the quality of the insulation. Perhaps it is unfortunate that these new proposals of the transformer subcommittee for higher dielectric tests make their appearance at a time when operating engineers are trying as never before to find ways and means of reducing the cost of electric service in order that it may be extended into rural districts heretofore considered uneconomical. The new test voltages have been questioned on the ground that they might lead to increased costs, or that they might preclude the possibility of certain cost reductions which otherwise could be made. I am, therefore, glad to see the data presented by J. K. Hodnette to show that from a practical manufacturing standpoint only an insignificant saving could be made in transformer costs by designing to lower test voltages. The savings possible certainly would not compensate for the reduction in quality which would result.

I wish to commend I. W. Gross on his excellent discussion. The questions he

raises in connection with insulation levels and impulse testing are of interest to all operating engineers. All of these questions have been raised before, but his discussion is evidence that they have not been settled.

The transformer subcommittee has not set up new insulation levels (except in the distribution transformer voltage classes); rather the committee has made use of the existing insulation levels which have been established by the 60 cycle insulation tests which have been in the A.I.E.E. standards for many years. The committee has attempted to define these insulation levels in terms of impulse strength, and to establish an impulse testing procedure which would demonstrate the existence of that impulse strength, not only in the major insulation (which could equally well be demonstrated by the 60 cycle test) but between the turns and layers of the winding (which can be demonstrated only by impulse tests).

Speaking for my own company, we have made commercial impulse tests on customers orders on approximately 50 transformers. These have ranged in rating from 45,000 kva to 200 kva for power transformers, and down to 200 volt-amperes for potential transformers. They range in voltage from 287 kv to 5.5 kv.

There were 3 failures on test within the first 6 months, but none since then. In these cases the transformers passed the A.I.E.E. 60 cycle test successfully, and the impulse tests revealed obvious defects which otherwise would not have been found. There have been no failures from lightning in the field. The first transformers were installed in the fall of 1931, so that some of the units have already seen 3 lightning seasons.

Gross seems to feel that by selecting the $1^1/_2$ x 40 wave shape and positive surges rather than negative we are not obtaining the required severity in our impulse tests. The question of severity is not one of wave shape or polarity, but rather the magnitude of the applied surge. Personally, I believe that some increase in severity of the test in the higher voltage classes should be made. See, for example, paper by F. J. Vogel in the *Electric Journal* for January 1935, entitled "Adequate Impulse Tests," also letter to the editor of *Electrical World* by F. J. Vogel, January 19, 1935. But in general it can be said that any appreciable increase in the severity of the impulse test will call for more insulation, correspondingly higher 60 cycle tests and correspondingly higher costs. I am sure the manufacturers would be quite willing to furnish transformers with more insulation at higher prices if they are desired.

The extent to which protection can be obtained with the co-ordinating gaps listed in table I of the paper has been indicated in several of the recent papers on insulation co-ordination; for example, "Factors Influencing the Insulation Co-ordination of Transformers—II," Electrical Engineering, June 1934, pages 870–6. In general we can say that the co-ordinating gap cannot be depended on for protection against direct strokes, but it will give protection against all ordinary traveling waves. The protection obtained is a matter of steepness of the wave front of the incoming surge.

In making a plea for the use of some simple, definite method of stating impulse strength, Gross voices a common desire. However, the practical difficulty of using definite kilovolt values in expressing impulse strength, as he suggests, is simply that the impulse strength of insulation is not a definite value in kilovolts. Its impulse strength depends on the wave shape, so that in expressing the impulse strength of an insulation structure in kilovolts it is necessary to state the particular wave shape for which the kilovolt value is given. Obviously this is a complicated method of expressing the impulse strength and, furthermore, does not express it completely, because it gives impulse strength for only one wave shape. The use of the equivalent gap also has its limitations because the time lag characteristics of various insulation structures are not exactly alike.

The proposed impulse flashover voltages for transformer bushings were established as follows: The bushing level was made as low as possible in order to obtain the maximum margin of co-ordination relative to the impulse strength of the winding, but sufficiently high so that when used in practice with the co-ordinating gaps of table I the gap would always flash over rather than the bushing.

In connection with Robert Treat's comments on the proposed changes in the impulse test procedure, I would like to say that these changes are not fundamental at all, but involve only certain simplifications which will reduce the labor and cost of making such impulse tests, and in certain cases will increase the severity of the tests slightly in the higher voltage classes.

Treat states that the second proposed test which specifies "A wave sufficient to flash over the bushing, provided standard bushings are used, and having a crest voltage bearing a definite relation to the 60 cycle test voltage" would seem to be a little dangerous unless it is very certain that the 60 cycle test voltages are so wisely selected, that when multiplied by this definite relation they always produce the correct value of impulse test voltage. The 60 cycle test voltages, have, of course, been in the Institute standards for a great many years. They do bear a rational relation to the circuit voltages, and they have formed the basis for the design of the major insulation on transformers ever since they have been in existence, and still do. The trouble with the present 60 cycle tests is not that they demand too much or too little insulation in high voltage transformers, but rather that they do not provide a test for that insulation which simulates voltage stress conditions in service at the time of lightning surges. The new impulse tests are designed not to change the magnitude of the major insulation in high voltage transformers which is established by the 60 cycle test voltages as in the past, but rather to give assurance that the same level of insulation strength is present within the winding (between turns and coils) under surge voltage conditions.

By establishing a maximum impulse test voltage which bears a definite relation to the 60 cycle test voltage, we are simply establishing an impulse test of the same relative severity as the 60 cycle test, so far as the major insulation is concerned, and then proving that that same insulation strength or level is present within the winding.

It is true, as Treat states, that if the bushing is to be flashed over the ratio of the maximum impulse test voltage required to the 60 cycle test voltage may in some cases be higher than the proposed ratio. This is actually the case with the proposed bushing standards. It will be found in the lower voltage classes that the power bushings have higher flashovers than the product of the 60 cycle test and the proposed ratio. For these classes (say up to 46 or 69 kv) the insulation is actually determined by the bushings for power transformers. This is not the case for the proposed distribution transformer bushings, where the proposed ratio multiplied by the 60 cycle test voltage will be practically sufficient to represent the bushing flashover.

If for some special reason transformer bushings having flashover voltages higher than the proposed standards are employed, it is of course obvious that correspondingly higher test voltages must be used if insulation co-ordination is to be maintained.

Portable Schering Bridge for Field Tests

Authors' closing discussion of a paper published in the January 1934 issue, pages 176–82, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 25, 1934, and other discussion was published in the March 1934 issue, pages 478–81, April 1934 issue, pages 618–22, September 1934 issue, page 1311, and July 1935 issue, pages 888–90.

C. F. Hill, T. R. Watts, and G. A. Burr: Probably one of the chief benefits to the electrical industry accruing from the presentation of our paper has been the wealth of test data brought forth by the discussers, which otherwise might not have been published.

Referring to the discussion by I. W. Gross, we regret his charge that we made a misleading statement when we said that "a portable instrument for the measurement of dielectric loss was not available for purchase and use by the power companies until the Schering bridge here described was developed." Having acknowledged earlier power factor tests in the field, in our abstract at the beginning, we were merely saying that the Westinghouse inverted Schering bridge outfit was offered for outright sale, while to the best of our knowledge the wattmeter insulation testing set had then been offered only in connection with special engineering service or on a rental basis. We believe that the existence of the wattmeter method, and also the commercial situation, were so well known to every one concerned that our statement was not misleading. We thought we were the first to use the Schering bridge in the field for bushing tests, but the discussion brought out the fact that the Schering bridge (not inverted) had been previously used in England for such tests. (B. L. Goodlet's discussion, April 1934 issue).

In regard to the relative merits of the bridge method and wattmeter method, we

believe there is but little advantage of either over the other as to the data given directly by the instruments. We are all agreed that the power factor is not the whole story, but the rest of the story is easily available, with the aid of a slide rule, from either set of instruments. It is immaterial whether we think in terms of power factor and watts loss, or in terms of power factor and capacitance, except that the former is easier with the wattmeter method, and the latter with the bridge method.

Probably the chief advantage of the inverted Schering bridge method over other methods is its ability to test transformer bushings having "fished through" leads without requiring much preliminary preparation. This advantage is explained in our original paper (page 181, right hand column) but evidently we did not lay sufficient emphasis upon it, since G. W. Gerell's discussion shows that he completely overlooked it. Admitting that his experience has been limited in the main to the use of the wattmeter set, he deplores the 15 to 20 man hours required to prepare a transformer unit for test. The elimination of this difficult preparation is an outstanding advantage of the inverted Schering bridge circuit The recent development of a current transformer attachment, by means of which it is hoped to duplicate this advantage with the wattmeter method, presents inherent difficulties which we believe will still leave the inverted Schering bridge circuit the preferable method for transformer bushing tests.

Concerning high power factor oil, this is usually the result of oxidation and for excessive oxidation may become quite high. It is for this reason and the accompanying sludging that we try to prevent oxidation. However, high power factor does not necessarily indicate low breakdown. As a matter of fact an oil with high power factor due to oxidation should have a higher dielectric strength than a new oil providing there is no moisture present. One of the dangers of the high acidity due to oxidation is moisture absorption which leads to lower strengths. The ordinary mechanical filtering removes solids, as suspended sludge, for example, and a dry filter process removes such moisture but will not remove the acids. These acids can be removed, but at an appreciable cost, and we are not convinced that such oils are worth reclaiming.

An Improved Electrothermic Instrument

Discussion and author's closure of a paper by P. M. Lincoln, published in the May 1935 issue, pages 474–81, and presented for oral discussion at the instruments and measurements session at the summer convention, Ithaca, N. Y., June 25, 1935.

True McLean (Cornell Univ., Ithaca, N. Y.): In his paper on "Rates and Rate Making" written in 1915, Prof. P. M. Lincoln showed that the instrument shown schematically in improved form in figure 6 of the present article is a true wattmeter. In the present article he has described improvements in the thermal and mechanical systems so that errors due to thermal and mechanical causes can be reduced to very small percentages. In all previous instruments of this general type, the errors were relatively so large that a rather crude electrical system was so much better than the rest of the apparatus, that refinements of the electrical system were a total waste of effort.

The improvements described are of such a fundamental nature that they eliminate thermal errors at their basic cause, without resort to nonlinear calibration scales or compensation tricks of any kind that might introduce other uncertainties of their own. The Bourdon tube construction results in such very large torques compared to other instruments that the mechanical system presents no problems of friction or balance. The net result is that as far as the thermal and mechanical system is concerned, the limit of accuracy is determined in the end by the reading errors of a conventional pointer and scale.

These important refinements make worthwhile, in fact necessary, a careful scrutiny of the electrical system. The requirements are briefly, that there must be produced in the closed secondary potential circuit (figure 6) a current which is strictly proportional to the line voltage, and exactly in phase with it. The liquid reservoirs require a power in the neighborhood of $^{3}/_{10}$ of a watt from the potential circuit to maintain a satisfactory temperature rise above ambient under no load conditions. Doctor Lincoln has shown that the best range of temperatures for various loads at various power factors is obtained when the circulating current is somewhat larger than the load current. Taking an arbitrary figure of 6 amperes for example in a nominal 5 ampere instrument, the total resistance of the 2 heaters is about 0.02 ohm. The heaters are made of an alloy having an extremely small temperature coefficient of resistance, and to minimize the coefficient of the entire circuit, the total copper resistance is held to less than 5 per cent of the heater resistance. This includes the secondary winding of the potential transformer directly, and also the primary winding reduced to equivalent secondary value.

Assuming for the moment an ideal potential transformer, it is easily seen that in a circuit of only about 0.02 ohm impedance, the stray inductance must be held to a very small value to prevent the circulating current from lagging behind the line voltage by an intolerable amount. A phase angle of 10 minutes of arc will produce an error in the meter reading of 0.5 per cent at 0.50 power factor, assuming the calibration correct at unity power factor. At standard 60 cycle frequency the total permissible inductance in the closed loop is only about 0.12 microhenry, or 12 perms, using a unit more convenient in this case. Still assuming an ideal transformer, and placing it as close to the heaters as a convenient arrangement of parts will permit, the total length of lead wires can be reduced scarcely below about 6 inches.

If we assume simply for ease of calculation, a transmission line, 3 inches in length, composed of a pair of 16 gauge wires with $^{1}/_{4}$ inch spacing, the inductance is 7.78 perms, over half the tolerance, allowing nothing for the leakage reactance of a practical transformer. Accordingly, the permeance of the closed loop was reduced as far as conveniently practicable by making the conductors of copper tape $^{5}/_{8}$ inch wide, separating each lead from its return companion by a layer of thin insulation, and lacing the combination tightly together. Using 5 mil tape and 5 mil insulation, the inductance is about 0.042 perm per inch of line as against 2.6 perms for the round wire spaced $^{1}/_{4}$ inch. The reduction of inductance in a ratio of roughly 60 to 1 in lead wires solved that problem, but the design of a practical transformer of small dimensions, and very low leakage reactance presented a problem. Since the resistance of botn windings must be kept low, and the secondary must be center tapped, a 2 turn secondary was used. By careful dimensioning of the windings it was found possible to keep

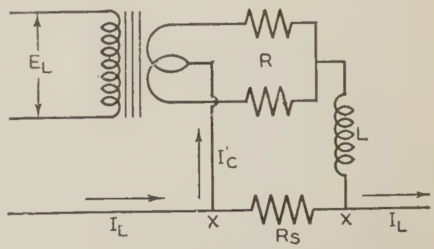


Fig. 1. Circuit for compensating phase angle errors

the leakage reactance safely within the limit and still have enough insulation to pass a 2,500 volt test.

In small transformers of only one watt output, the greatest difficulty encountered when striving for a small phase angle, is the angle between line voltage and induced electromotive force. The magnetizing current which is in lagging quadrature with the voltage produces a resistive drop in the primary winding. This effect is extremely small in power transformers, but becomes of major importance in very small designs. The effect is reduced in good instrument transformer designs by using windings all out of proportion to the wattage ratings. High permeability alloy cores do not offer a solution in this case because the principal reluctance in the magnetic circuit is due to the minimum air gap attainable with commercial punchings. There appeared to be only 2 ways out of the difficulty; either to use a ring core and toroidal winding, or considerably increase the bulk of the design. Neither of these ways is satisfactory from the standpoint of cost.

Prof. W. C. Ballard suggested that a way out was to shift the phase of the load circuit current by an amount just equal to the unavoidable shift in the potential circuit, and thereby attain perfect compensation at any load power factor.

The addition of a resistive shunt around the load circuit in combination with a small inductance connected between the shunt and the potential circuit accomplishes the double purpose of permitting perfect phase adjustment and also extending the range of the nominal 5 ampere instrument to any desired higher value.

The electrical circuit of the meter may be conveniently redrawn as in figure 1. The line current is designated as I_L; and the total current through the heaters due to the load, as I_C. R_S is the resistance of the non-

inductive shunt, R and L are the total values of resistance and inductance of the heater circuits measured between the junction points X-X and include heaters, transformer secondary, lead wires, and loading coil. The quantity of interest is the complex ratio of the currents I_L/I_C which expresses both the magnitude of the increase in line current due to the diversion of the shunt and the phase shift introduced. By straight forward circuit analysis the resulting expression is

$$\frac{I_L}{I_C} = A\epsilon^{j\alpha}$$

where the modulus $A \geqq 1$ for all values of R_s from zero to infinitely large, and has the value

$$A = \sqrt{\left(\frac{R}{R_S} + 1\right)^2 + \frac{\omega^2 L^2}{R_S^2}}$$

and the argument α, has the value

$$\alpha = \text{arc tan}\,\frac{\omega L}{R + R_S}$$

It is interesting to note that for a given instrument, the values of R_S and L may be independently chosen, within reasonable limits. The theoretical limits are

$$R_S \xrightarrow{lim} \infty\ A = 1 \text{ and } R_S \xrightarrow{lim} 0\ A \longrightarrow +\infty$$

$$\text{also } R_S \xrightarrow{lim} \infty\ \alpha = 0 \text{ and}$$

$$R_S \xrightarrow{lim} 0\ \alpha = \text{arctan}\,\frac{\omega L}{R}$$

The practical limits on the shunt resistance are determined by simple considerations. The lower limit is reached when so large a fraction of the line current is diverted that the heater current becomes inconveniently small. The upper limit is determined by the size of inductance that can be built with reasonable bulk, remembering that the total resistance R includes the coil, and the portion of R external to the actual heaters is restricted to 5 per cent of the total. This is assuming that an adjustment is being made to a value of α predetermined by the characteristics of a practical potential transformer.

Since the phase shifts which are due to primary winding resistance and due to secondary circuit plus leakage inductance, are in opposite directions, they can be made to cancel if the design is carefully worked out; then no compensation is required. The circuit of figure 1 compensates for lagging current in the heater circuit. If the primary resistance effect predominates, the compensation is reversed in direction by connecting the inductance in series with the shunt R_S instead of in series with the heaters as shown.

With a method at hand to correct completely for any reasonable phase shift in the potential transformer, the temptation at once appears to select a transformer as small and cheap as possible, since its lag can theoretically be completely compensated, however bad it may be. In doing this, however, there is danger of a second order error becoming appreciable. The magnetizing current of the transformer which is responsible for most of the total lag is a nonlinear function of the line voltage, and consequently if a close compensation is depended on at rated voltage, there will be a power factor error in the instrument when the line voltage departs appreciably from the value for which the compensation was adjusted. The best course, therefore, appeared to design for the best transformer characteristics practicable at reasonable cost, considering the space restrictions of the instrument case. Compensation may be then applied by choosing a shunt resistance that gives a reasonable diversion of load current and an inductance of small bulk.

After choosing approximate values for the shunt and phase correcting inductance from the above considerations, a final adjustment of each can be made in each individual instrument after assembly. Filing the edges of the shunt of course brings the deflection to the proper point on the scale and is a sensitive means of final calibration. The final adjustment of phase correction may be accomplished to a high degree of precision by observing that the currents due to the load and due to the potential transformer are in opposition in one of the heaters. If the load is a pure resistance, the phases of the 2 currents are exactly opposite, except for the shift due to the potential transformer. At a critical value of load resistance, the current through the heater may be made to just pass through zero, provided that the phase correcting inductance has the right value. Accordingly, an a-c voltmeter is connected across the heater through a fairly high gain amplifier, which gives an ordinary recti fier type instrument sufficient sensitivity for the purpose. The inductance inserted is made lightly too large, and reduced to the exact value by deforming the coil. Since this is a null method, the amplifier need not be calibrated.

The electrothermic instrument appears now to have reached a stage of development where its performance compares favorably with high grade laboratory instruments.

P. A. Borden (The Bristol Co., Waterbury, Conn.): It is the practice of designers of pressure gauges and thermometers involving the opposed action of Bourdon springs or bimetallic elements to provide some form of differential device permitting each element to deflect freely without restraint. In the development of the several forms of thermal ammeters and wattmeters for which Prof. P. M. Lincoln has been responsible, this feature has doubtless received intensive study. Since Professor Lincoln has standardized on the form having the elements directly in opposition, it is to be assumed that he has found the restraint so imposed on the expanding elements to have no ill effects on the accuracy or permanency of the calibration. A summary of Professor Lincoln's experiences in this connection would be of interest.

Paul MacGahan (Westinghouse Elec. and Mfg. Co., Newark, N. J.): I think we will generally agree with Prof. P. M. Lincoln in the idea that the exponential or logarithmic meter is not only consistent with the standard definition established for demand, but that it also gives a reasonable approximation to representing the "fixed charge" factor of the service demanded. Thus it gives a basis for dividing such costs equitably between different consumers, according to the character of the load.

In order to be acceptable as a standard, a meter must be such as to facilitate calibration in terms of standard units. The important point is not whether we measure a commodity in pounds or in bushels, on a block interval basis or on a logarithmic demand basis, but whether the unit used is readily reproduced for calibration, and whether it is acceptable to both buyer and seller.

When Professor Lincoln developed the earliest type of thermal demand meter, I recollect that I was of some assistance in influencing his development away from the earliest form, which had liquid sylphon type of expanding units, and adopting the bimetallic strip element.

While that construction resulted in a practical instrument, problems of the errors due to heat dissipation control were still present, and the resulting difficulties in accurate calibration undoubtedly retarded the general application of thermal meters.

This thermal meter difficulty, as associated with the previous meters, must not be confused with the general subject of logarithmic or exponential principle of demand charging as it can only apply to such earlier demand meters as operate on the electrothermal principle. In such meters the electrical energy of the windings is first converted into heat and then the effect of the heat is measured through expansion of bodies which, in turn, move the pointer across a scale.

It does not apply to lagged demand meters, which operate electro-mechanically, such as the Hall meter (Patent No. 1,331,-059), the Boddie meter (Patent No. 1,408,-255), or the meter described in the paper "A New Demand Meter," B. H. Smith, ELEC. ENGG. (A.I.E.E. TRANS.) v. 53, Jan. 1934, p. 94–6.

This latest instrument, as described by Prof. Lincoln, apparently eliminates the earlier difficulties which for many years seemed to be unalterably associated with thermal instruments.

It should revive general interest and confidence in the logarithmic method of measuring demand.

P. M. Lincoln: A gentleman has asked if dimensional analysis has been applied to the solution of the problems arising in connection with this improved meter. No attempt has been made to apply this method of analysis. I do not see at the moment that this method of analysis can have any application, but I wish to thank the gentleman for his suggestion.

A gentleman has asked what is the minimum amount of power that may be measured by this improved instrument, and has specifically asked if one watt could be measured. One watt can certainly be measured but the accuracy of measurement would depend upon unspecified conditions. If one watt were applied to a 1,000 watt wattmeter, the accuracy would certainly be low. If it were applied to a 10 watt wattmeter, a high degree of accuracy could be obtained.

A rather loose statement which is contained in the appendix of the paper should be pointed out. In the appendix the statement is made that $\frac{d\,V_t}{dK_t}$ becomes a constant when $\alpha + \beta + \gamma = c(\alpha' + \beta' + \gamma')$. To a mathematician it is obvious this is not true

unless and until $\alpha = c\alpha'$, $\beta = c\beta'$ and $\gamma = c\gamma'$, c having the same value in each case; that is, until the coefficients of each power of t bear a given ratio to each other. For all practical purposes, however, the statement is true as it stands; this is because in actual application, the effects of the β and γ coefficients are practically negligible.

P. A. Borden has pointed out that it is common practice when Bourdon tubes are used opposing each other to permit of free deflection by using some sort of differential device. May I say that this point has been thoroughly considered, and exhaustive tests have been made with the tubes disposed as Mr. Borden suggests, and also with the tubes directly opposing each other as I suggested in my paper. While it is undoubtedly true that the limitations of the Bourdon tubes when used as I propose are somewhat less than if used as Mr. Borden proposed, my tests have shown that there is not sufficient gain in the yield point of the tube material by such method of use as to justify the additional cost of the differential mechanism.

Direct Measurement of Surge Currents

Discussion and authors' closure of a paper by C. M. Foust and J. T. Henderson published in the April 1935 issue, pages 373–8, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935.

W. W. Lewis (General Elec. Co., Schenectady, N. Y.): It may be of interest to list some applications of surge crest ammeter magnets which have been made in the past 2 or 3 years. The towers of the following lines have been completely equipped, in some cases with 4 brackets and in the remainder of the cases with one bracket per tower: The Pennsylvania Power and Light Company's 220 kv, 65 mile Wallenpaupack-Siegfried line, the Appalachian Electric Power Company's 132 kv, 65 mile Glenlyn-Roanoke line, the Pennsylvania Water and Power Company's 220 Kv, 70 mile Safe Harbor-Westport line, and the Philadelphia Electric Company's 66 kv, 14 mile Philadelphia-Chester line.

The Pennsylvania Power and Light Company and the Appalachian Electric Power Company have equipped portions of their ground wire and counterpoise installations, also crossarms and vertical lightning rods at some towers have been equipped.

Distribution circuit lightning arrester down leads have been equipped at about 1,000 locations in Chicago, Detroit, Boston and Atlanta.

The principal broadcasting towers in eastern United States have been equipped with magnets. Miscellaneous applications have been made on station lightning arrester ground leads, lightning rod installations, etc., in various parts of the country.

All told, about 12,000 magnetic links have been installed in the past 3 years.

Currents up to 100,000 amperes per tower have been measured and up to 220,000 amperes total in all the towers affected by one stroke. In the distribution lightning arrester circuits, currents up to 10,000 amperes have been measured. Currents up to 50,000 amperes have been measured in broadcasting towers.

The majority of currents in all classes of installations have been of negative polarity. The larger currents, as a rule, are unidirectional with the smaller currents tending to be oscillatory.

It has been possible in the case of some of the more complete installations to tell whether the stroke hit the conductor, tower, or ground wire; and thereby to evaluate the efficiency of the ground wire arrangement.

K. B. McEachron (General Elec. Co., Pittsfield, Mass.): The authors have described a method of measurement of surge currents which is simple and reliable, and which will yield information not only of magnitude of current but direction and degree of oscillation, if present. A large number of these magnetic links are now in service and have already added considerably to our knowledge of the lightning discharge and its effects on lines and towers.

Between magnetic links there is some variation which results in some loss in accuracy, however, in those cases where more accurate readings are desired, the magnetization may be determined with the ballistic galvanometer, after which the magnetization curve may be taken giving a close calibration of the link. This method has the advantage that it is only necessary to examine more accurately those which have interesting records, thus making it unnecessary to make such determinations on the majority of the links in service.

It seems to me that considerable care should be exercised with reference to the interpretation to be placed on records which show the presence of reversed current. It is probably true that in most cases the links as used will not be materially influenced by the presence of power follow current. However, it is a factor which should be considered when reviewing data from locations where power follow might occur.

It does not seem to me that the data thus far accumulated will justify the conclusion that lightning oscillates, although the presence of reverse current has been found in a considerable proportion of the records. Voltage reflections in towers may occur, but these do not give rise to reversed currents. It may be that the measurement of reversed current is the result of the combination of the induced and direct stroke effects. It is well known that the induced potential will be of opposite polarity from the direct stroke, and thus a measured reversal could be accounted for which is not in the direct stroke itself.

If the reversal is the result of a combination of induced and direct effects, certain evidence should be found to substantiate this idea. In most cases, at least where the overhead ground wire was struck, reversal might be expected, but if the stroke occurred in the vicinity, but not to the ground wire, then induced effects alone would give rise to current, but without reversal. It seems to me likely that data from measuring instruments, located at the upper end of conducting structures, would give the most certain information concerning the current in the direct stroke itself. I feel that more data under less complicated conditions will have to be obtained before we can make a definite statement concerning oscillation in the stroke itself.

Another factor in interpreting the record from the magnetic link that must not be lost sight of is the inability of the link to indicate whether or not the reversal occurred within one stroke or whether it is associated with separate but multiple strokes, or whether the reversal resulted from independent effects which may have had considerable separation in time. All of this indicates the necessity of not drawing conclusions too hastily from insufficient evidence.

C. L. G. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): I consider this paper by C. M. Foust and J. T. Henderson to be a most lucid statement of the theory of the surge crest ammeter. The method of measuring the degree of magnetism retained is most ingenious. I am convinced that with this instrument reliable measurements of unidirectional surges can be obtained. I am not convinced of the reliability of the device for obtaining data on oscillatory surges, nor of the interpretation of some of the readings in terms of oscillatory surges. In short, I do not believe that there are oscillatory discharges in a lightning stroke and that if any are indicated they are probably, as K. B. McEachron has pointed out, due to positive unidirectional surges arising from induction from a lightning stroke external to the line, superimposed on the negative unidirectional surge due to a direct stroke.

This suggests the need of great caution in the interpretation of values of surge potential indicated by these little devices, for if, let us say, one of them has been subjected to a negative potential of 100 per cent during a thunderstorm, and during that same storm to a number of positive induced surges varying from 1 per cent to 10 per cent, would not the demagnetizing effect of the positive induced surges be cumulative in reducing the retained magnetism caused by the first surge? In this respect the method developed by the Detroit Edison Company based on the calibration of a hole burned in a piece of paper between flat copper plates has points of merit, because if a heavy negative surge has burned a hole in the paper any number of positive surges following certainly cannot unburn the hole already found so that this method within its range of reliability will give a measure of the maximum surge to which the device has been subjected. The possible demagnetizing effect of succeeding surges of opposite polarity to that due to the lightning stroke surge appears to me to be the weak point in an otherwise admirable and intriguing device.

For this reason I agree with P. L. Bellaschi that data from all sources and means of measuring lightning currents should be weighed and given fair consideration in determining the yearly distribution of current magnitude in lightning strokes that terminate on a transmission line. Some of the records obtained in the past by the surge recorder showed values as high as 800,000 amperes for the total current in a lightning stroke. When checked against values obtained by computation from data reported by other methods, such as the total quan-

tity of electricity found by ballistic methods, it was decided that these values were so large that there must be some mistake in calibration and later on this was found to be the case. More recent measurements with the surge recorder shows maximum values of the order of 190,000 amperes which appears to be about right. When the first results from the surge crest ammeter were published the maximum recorded value was 70,000 amperes as I recall, making a possible value for the lightning stroke of the order of 100,000 amperes. There had been too many records to ascribe the low value to the absence of strokes of maximum severity, so I am compelled to assume that all factors such as the amount of current flowing in alternative paths (for example displacement currents and those in adjacent towers) had not been fully accounted for. It is interesting to note that values derived from crest ammeter readings are on the upgrade again and maximum values of 200,000 amperes total surge current, including reflection, have been recorded

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The recent work by C. M. Foust, W. W. Lewis, Philip Sporn, and Edgar Bell in this country and the similar investigations by Grunewald in Germany confirm the suitability of magnetic links for recording lightning currents. Another device, employed by Collins to measure lightning currents in the ground leads of arresters, comprises 2 metal disks separated with thin paper insulation. Still a third method consists in comparing directly the effects associated with natural lightning to similar results obtained with lightning stroke current generators in the laboratory. This third method has been used at the Sharon laboratory for the past 2 years. The more common field experiences on lightning stroke currents investigated in the laboratory have been associated largely with the following physical effects:

1. Fusion of conductors.
2. Crushing of conductors and tubes.
3. Surface burning of conductors.
4. Explosive and shattering effects.
5. Magnetic and magnetizing effects.
6. Characteristics of lightning arc.
7. Other effects.

The extensive data on the fusion and crushing of conductors establish that lightning stroke currents infrequently exceed crest values considerably greater than 100,000 amperes. Multiple strokes apparently account for the severe crushing of conductors and the fusion of heavy conductors. *This third method has also yielded valuable data on the physical characteristics of the lightning channel.* It is found that the lightning current arc when restricted or confined develops pressures in the order of 10,000 to 20,000 pounds per square inch. It is also established that the core of the lightning stroke channel has a diameter of one to 2 centimeters.

Lightning current distribution curves established from field records obtained by the different methods of measurement indicate a substantially similar trend. The current amplitudes range from about 10,000 amperes to a maximum in the order of 150,000 amperes.

With the modern facilities and refinements for calibrating magnetic links, more and more dependable data from this method of measurement should be forthcoming in the future. It will however be through a correlation of all the data available that comprehensive information of the magnitude, wave form and duration of the lightning stroke currents can be fully established.

S. K. Waldorf (Pa. Water and Pwr. Co., Baltimore, Md.): The work on the calibration of surge crest ammeter links by Messrs. C. M. Foust and J. T. Henderson is of great interest and importance to everyone dealing with lightning phenomena, particularly to those employing the links for the measurement of lightning currents in transmission towers. At the beginning of the summer of 1934, the Pennsylvania Water and Power Company equipped one leg of each of the 477 towers of the Safe Harbor-Westport 230 kv line with a bracket holding 2 surge crest ammeter links. This season the study has been extended to a 69 kv line and a 132 kv line. The former has 227 towers and the latter 179 towers, making a grand total of 883 towers equipped with these links, of which 85 towers have a bracket and 2 links on each of the 4 legs.

The additional data presented in this paper appreciably affects our interpretation of the lightning current records obtained with surge crest ammeter links. The link calibrations originally provided with the surge crest ammeters were for unidirectional currents only, and in using them for links magnetized by actual lightning currents in transmission towers, discrepancies at once became apparent. The nature of these discrepancies is indicated in the accompanying table I of some sample records obtained in 1934 on the Safe Harbor-Westport line. The examples cited are not isolated inconsistencies, but in each case are representative of a number of records of the given type.

Consideration of the simple electromagnetic principles involved leads one to expect the magnetization of the links to be inversely proportional to their respective distances from the current center of the tower leg to which they are connected. All of the records given in table I were obtained on towers having 5 inch by 5 inch legs on which the "distance ratio" of the links is $^9/_3 = 3$. For non-oscillatory currents, the deflections caused by the inner and outer links theoretically should bear this same ratio. Examination of table I shows deflection ratios ranging from zero to infinity. In most cases, the deflection ratio was found to be between about 1.5 and 2.5 in the records obtained last summer, indicating that the great majority of tower currents were not unidirectional.

The new oscillatory calibrations now provided by the authors theoretically will care for those cases where the ratios of deflections range from zero to the value of the corresponding distance ratios. In table I, the third, fourth, and fifth items are in this classification and the readings can be interpreted satisfactorily, and in the sixth item where the inner link showed no magnetization and the outer link showed some, an approximate method of evaluation has been provided. In the first 2 items of table I, where the deflection ratios are greater than the corresponding distance ratios, no evaluation is yet possible except by assuming a unidirectional surge. If a unidirectional surge caused the records of the first item, the outer link would be expected to show an appreciable deflection of at least 3 or 4 divisions on the surge crest ammeter. It is possible that an oscillation occurred which was of sufficient magnitude to reverse completely the magnetization of the inner link and demagnetize the outer link. We wish to inquire if this explanation seems reasonable to the authors or if they have found some other cause of the observed phenomenon.

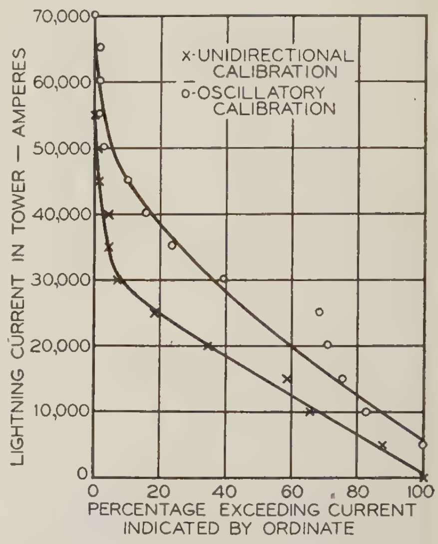


Fig. 1. Currents indicated by magnetic links on towers on Safe Harbor-Westport line believed struck by lightning in 1934

Table I—Sample 1934 Tower Lightning Current Records

230 Kv Safe Harbor-Westport Line of the Pennsylvania Water and Power Co.

Tower Number	Surge Crest Ammeter Readings: Inner (1 inch) Link	Outer (7 inch) Link	Ratio	Tower Currents in Amperes: Unidirectional Calibration: Inner Link	Outer Link	Average	Oscillatory Calibration
67	−15	0	Inf.	10,400	0	10,400*	10,400
28T	−14	− 2	7	9,600	4,000	6,800	10,000
337	−44	−18	2.4	30,000	37,400	33,700	42,800
169	−26	−16	1.6	18,000	32,800	25,400	42,000
168	−11	−12	0.9	7,500	4,000	5,700	32,400
115	0	−11	0	0	22,400	22,400*	48,000

* Zero records were considered as being inaccurate and therefore were not included in average.

Table II—Comparison of Unidirectional and Oscillatory Calibrations of Magnetic Links on Typical Towers Believed Struck by Lightning

1934 Records From 230 Kv Safe Harbor-Westport Line of Pennsylvania Water and Power Company

Tower Number	SCA Deflection: Inner Link	SCA Deflection: Outer Link	Tower Amperes: Unidirectional Calibration	Tower Amperes: Oscillatory Calibration	Tower Potential in Kv: Unidirectional Calibration	Tower Potential in Kv: Oscillatory Calibration	Ratio of Oscillatory to Unidirectional
62T	+60	+20	44,000	44 000	308.0	308.0	1.00
330	−45	−16	32,000	37,000	32.0	37.0	1.16
121T	−52	−27	55,000	70,000	660.0	840.0	1.27
303	−51	−22	40,500	53,000	324.0	424.0	1.31
120	−28	−15	30,000	43,500	720.0	1045.0	1.45
323	−26	−13	22,000	33,600	440.0	672.0	1.53
169	−26	−16	25,400	42,000	1220.0	2020.0	1.66
315	−10	−10	14,000	28,000	294.0	588.0	2.00
172	0	−12	24,800	48,000	1040.0	2020.0	1.94
60	0	−10	20,800	48 000	810.0	1870.0	2.31

Much of the difficulty in evaluating the surge crest ammeter deflections occurs for those cases where the deflections are small, that is, where the deflection of one of a pair of links is less than 10 divisions on the surge crest ammeter and the accuracy of the meter readings is low. The first two and the last items of table I fall under this classification.

Aside from the importance of being able to determine correctly the current flowing in the angle iron of towers on which the links have been mounted, it is of importance that the true significance of the indicated oscillations be known. This is brought out by consideration of the accompanying curve and the data of table II in which tower potential is the product of tower current and tower footing resistance. There has been considerable evidence accumulated indicating that flashover of transmission towers due to lightning does not occur if the product of tower footing resistance and tower crest surge current does not exceed the flashover value of the insulator string. [See "Lightning Investigation on Transmission Lines," W. W. Lewis and C. M. Foust, Elec. Engg. (A.I.E.E. Trans.), v. 53, Aug. 1934, p. 1180–6.] These data for the most part have been based on the unidirectional calibration of the surge crest ammeters. As can be seen from the graph and table II, the oscillatory calibrations indicate larger crest currents, and consequently higher tower potentials, than the older calibration and all of the accumulated data may no longer support this theory if interpreted in the light of this new work. Table II shows that tower potentials indicated by the unidirectional calibration were all appreciably below the flashover value for the given line, but as now interpreted, the highest were apparently dangerously close to the maximum permissible value of about 2500 kv for the tower top, but still conformed to the theory. Also, the maximum tower current which we have recorded is raised from about 55,000 amperes to 70,000 amperes.

The apparent oscillations may be an indication that cross and diagonal members of transmission towers have a greater effect on surge crest ammeter readings than at present allowed for. It is possible that the closed loops formed by the tower members are subjected to local oscillations of radio frequency, affecting the link readings, and that the recorded currents are local and not indicative of the current in the tower as a whole. Another possible effect is that the diagonal members carry appreciable current to ground in addition to that conducted by the four tower legs and for which no allowance is made at present. It will be interesting if the authors will tell us whether the calibrations of the links have been checked under field conditions by sending surges of known characteristics through actual tower structures.

L. A. Eggleston (Natl. Aniline and Chem. Co., Buffalo, N. Y.): I raise the question as to how to reconcile the various sets of lightning data, some of which are based on surge crest measurement and instrument values, as against other sets of data based upon burning effect or pressures, which must involve an effective value with a variable time axis due to different surge frequencies.

C. M. Foust and **J. T. Henderson:** Discussion on this paper was confined almost entirely to the interpretation of field records, and dealt particularly with those records wherein some degree of current oscillation was indicated. The material included in the paper presented was selected in an effort to give a clear description of a new surge current measurement technique. The few field records included in the paper served only to complete the description of this new method. A very great number of field records have been obtained and these will be analyzed at a later date

The use of the surge crest ammeter for lightning currents proved conclusively for the first time by direct measurement the negative and unidirectional polarity characteristics of these currents in transmission line structures. In general, for lightning stroke currents of the higher order of magnitudes the 2 link measurement stations show quite conclusively a single direction of current flow. For the lightning currents of lower order of magnitude some degree of oscillation is sometimes indicated.

As pointed out by K. B. McEachron, these records should not be hastily interpreted as proving that lightning currents sometimes oscillate, although it is clear that they do show the presence of some degree of current reversal in the line structure. Mr. McEachron suggests that this current reversal may be due to a combination of induced and direct effects. Such records would be obtained only when the direct stroke currents and the induced currents were not simultaneous. Detailed study of records now being obtained in various parts of the line structure will quite likely give more information on this point.

C. L. Fortescue called attention to the possible cumulative effect of reversed currents in reducing the retained magnetism caused by the first surge. Such a demagnetizing effect is, of course, a possibility but our records indicate it to be a very uncertain one. That such a reduction takes place does not appear reasonable in view of the many records already obtained, especially at high currents where inner link-outer link ratios indicate the presence of unidirectional currents. Such records could be obtained only in the absence of such a cumulative reduction in retained magnetism.

S. K. Waldorf called attention to a case where an inner link showed some magnetization and the outer link practically none, and suggested an oscillation of sufficient magnitude to reverse completely the magnetization of the inner link and demagnetize the outer link. While it is true that some possible combination of successive surge currents might produce such an effect, we do not consider such an interpretation to be justified in view of our available calibration data. In our laboratory calibrations we used surges of constant decrement up to 50 per cent oscillation over a wide range of amplitudes, and in all cases obtained inner link-outer link ratios less than the distance ratio. It appears more reasonable to attribute such records to the circumstance that Mr. Waldorf refers to immediately following and which pertains to difficulties in interpretation where surge crest ammeter deflections are small. We believe it good practice to follow the rule of omitting oscillatory interpretations unless both links give surge crest ammeter readings between 10 and 100.

Mr. Waldorf also calls attention to the correlation between insulator assembly flashover records and corresponding tower potentials obtained from surge crest ammeter currents and tower footing resistances. In general, this correlation seems to be better for the currents obtained from the oscillatory calibrations than from those obtained from the older unidirectional calibrations. This kind of analysis can be properly evaluated of course only after the accumulation of a great number of records. Uncertainties such as the real value of the footing resistance under surge current conditions and the wave shape of the tower potential also now prevent final conclusions on this point.

In answer to Mr. Waldorf's inquiry concerning laboratory calibrations we did not use a complete tower structure and as yet have not studied the possible effect of currents in the diagonal members. In the laboratory, surge currents were passed through angle iron sections similar in size to tower legs. A surge generator of considerable size would be required for actual field calibrations on full size towers at current values of 50 to 100,000 amperes.

L. A. Eggleston raised the question of accuracy of crest current values as obtained by the direct magnetic method and by burning effect or pressures. Undoubtedly, the

size of a hole burned in a piece of paper depends upon current and time, and the results obtained are dependent upon the use of laboratory surges for calibration having the same time elements as the surges to be measured. The authors feel very decidedly that the magnetic method, especially when 2 links are used, is productive of values of greater accuracy.

Lubrication Increases Life of Meter Bearings

Discussion and author's closure of a paper by T. A. Abbott and J. H. Goss, published in the April 1935 issue, pages 428–31, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935.

L. D. Price (Public Service Elec. and Gas Co., Paterson, N. J.): As the authors have pointed out, developments in watthour meter design over the period of the past several years have left the lower bearing as probably the one remaining weak spot in the meter. Realizing this and attempting to gather further knowledge of meter bearings, the Public Service Elec. and Gas Company is conducting a laboratory test on 306 watthour meters at Paterson, N. J. The purposes of the test are to study the effect of varied degrees of lubrication on sustained meter accuracies, to ascertain the causes of jewel failure, and, if possible, to determine the maximum length of test schedule economically possible under present operating conditions. The meters are representative single element meters of American manufacture; both natural and synthetic jewels are being used and the tests are conducted under classification 2 of the suggested means of obtaining test data at normal speeds under various loading conditions designed to approximate actual service conditions. We felt that this method of test was preferable to the accelerated test because of the time factor involved in the possible breaking down of the lubricant.

Although the test has not progressed to a point where many definite deductions can be drawn, there is sufficient evidence to support the authors of this paper on one contention; namely, that in a bearing of the pivot type, liberal lubrication is essential to sustained meter accuracy.

Our test has raised a number of questions, however, that we should like to pass on to the manufacturers for their consideration. The new jewel mounting described in this paper answers the very important question of lubrication, and we hope that this is the beginning of a development comparable to the very fine progress made in the past several years in improving load and temperature characteristics, and in the standardization of physical dimensions.

Furthermore, we should like to emphasize the importance of cleanliness as a factor in proper lubrication. We have found that dirt or foreign material present in the jewel cup absorbs a considerable portion of the oil and after a short time forms a gummy substance that increases the frictional torque of the meter appreciably. This condition also interferes with lubrication and tends to increase corrosion of the pivot. We suggest that replacement jewel screws and pivots be sealed in individual moisture proof and dust proof containers, such as capsules or cellophane envelopes.

In attempting to ascertain the cause of jewel failure we have formed several theories based upon our observations. Under the general heading of insufficient lubrication we have the formation of rust, which is undoubtedly a ferrous oxide with traces of carbon and other elements. This rust may act in one of 2 ways, or both; namely, (1) some of the rust particles may be of the same relative degree of scratch hardness as the sapphire jewel and form a grinding compound, or (2) the corrosion roughens the surface of the pivot so that under the tremendous pressure microscopic projections on the pivot dislodge microscopic fragments from the jewel surface and these eventually form a grinding compound. In other words, a polishing process starts and gradually advances to the grinding stage. This latter theory is substantiated by several observations that have shown worn and polished spots prior to jewel breakdown.

Well lubricated jewel bearings with no trace of corrosion on the pivot often show scratches and are badly ground up within a few million revolutions. Here again we have 2 possible answers. In the process of mounting the jewels by crimping and/or spinning, strains are set up in the jewel. These strains sometimes result in transverse cracks, but more often cause small fractures to appear at the rim of the jewel. Small particles of sapphire, loosened by the fracture, fall into the cup and form a grinding mixture. The second cause of this same condition is to be found in the handling of meters, the impact of pivot against jewel apparently being sufficient to scratch or chip the sapphire. Examination of jewels removed from new meters shows a surprising number of damaged jewels, and this is probably the cause of the failure of so many bearings after short service. Great care is exercised by the manufacturers to protect the meter case and glass cover from injury during shipment but only on polyphase meters are the shafts blocked so that the pivot is off the jewel. To guard against these controllable factors involving jewel life, we recommend, therefore, first the development of a more satisfactory method of jewel mounting and secondly the application of removable blocks under the disks of all meters, when packed for shipment.

Since the manufacturers are so much better equipped for research than the operating companies, we should like to suggest 2 major subjects for their consideration. First, the use of a noncorrosive, possibly nonmetallic pivot. It seems probable that a composition pivot with reasonable elastic constants might be developed. Second, the use of lubricants of heavier body than oil. A lubricant of the consistency of vaseline at normal temperatures, that would withstand zero temperature without hardening would be very desirable in keeping foreign materials from being precipitated to the jewel surface.

In conclusion, we hope that the development of the perfect bearing will progress and that we shall eventually be able to standardize on one bearing for all makes of meters, with the resulting economies and conveniences inherent to standardization. We realize that the problem of the superiority of the pivot type bearing over the ball type or *vice versa* will never be settled. We do not know that either type is now perfect. Utility companies are "jewel bearing conscious" and we should certainly appreciate the co-operation of the manufacturers in the solution of this problem. Between us, we should get the answer.

M. W. Pullen (Johns Hopkins Univ., Baltimore, Md.): T. A. Abbott in his presentation emphasizes the enormous bearing pressures in meter pivots; and, further, that pivot wear reducing this pressure to approximately 2,000 pounds per square inch affected the meter calibration but slightly. The authors state it is apparent that it is impossible by any reasonable manufacturing process to shape the pivot to give this initial pressure, however deviable it may be. It seems to me that the manufacturing process will be developed if the demand is great enough. The advantages are certainly obvious. The authors have not stated what kind or character of oil they use, and whether it is put in the bearing before the meter is shipped or when it is installed? If the former, what keeps it from leaking out during shipment so rendering the condition of the meter bearing to be no better than without any lubrication?

J. H. Goss: L. D. Price pointed out that cleanliness is an important factor in bearing life. This is certainly true in that a hard gritty material in the bearing probably would accelerate wear and the presence of an organic material could possibly contaminate the lubricant.

The suggestion that heavy lubricants approaching the consistency of petroleum jelly be used to give better protection for the bearings is subject to the limitations of the available lubricants. For a limited temperature range petroleum jelly will give good performance, but at low temperatures the material becomes thick and viscous. For this reason it is necessary to use lighter oils that have a low temperature coefficient of viscosity. The problem of a heavy lubricant with a flat temperature-viscosity characteristic must rest with the oil chemist for solution.

The use of new bearing materials as suggested has been the subject of particular interest to meter manufacturers during the past few years. It is quite possible that some improvement will be made in the bearing by the use of a nonferrous material for the pivot.

It is gratifying to note that Mr. Price's data substantiates our own for certainly the utility companies are in a best position to obtain data on bearing performance as their entire system can be turned into a testing laboratory if desired.

M. W. Pullen pointed out the necessity for a stable bearing lubricant.

The lubricants for bearings that are available are in the majority of cases the product of years of development and research and embody the latest improvements in the field of lubrication. The lubricant used in obtaining the data presented in this paper will satisfactorily withstand a temperature of 75 degrees centigrade for 50 days

with a very small evaporation loss and a negligible increase in viscosity.

Mr. Pullen further suggests that the area of the pivot be pre-formed to give the correct contact area as shown by figure 2. It is not practical to do this as it would require that only 28×10^{-6} inches be ground off the end of the pivot to give the area necessary if a pivot with a radius of 0.0185 inches is used. A further difficulty is that the radius of the jewel cup is not held closely enough to allow the pivot contact area to be pre-formed even if it were mechanically possible.

Step Type Feeder Voltage Regulators

Discussion and author's closure of a paper by L. H. Hill published in the February 1935 issue, pages 154–8, and presented for oral discussion at the distribution and transmission session of the South West District meeting, Oklahoma City, Okla., April 26, 1935.

F. L. Snyder (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): As pointed out by the author the development of the step type voltage regulator was the natural result of the experience of both manufacturers and operators with load tap changers on power transformers. As a matter of fact, there is nothing new about the theory of a step type regulator. Several manufacturers of electrical machinery have been building step type regulators for the past 10 years and there are several million kva of installed capacity of such equipment. Step type regulators of the type which manufacturers have been building for some time have, however, been too expensive for application to distribution circuits and the step voltage regulator of the general type described in this paper consists of a smaller and less expensive regulator which can be economically justified on distribution circuits. Apparatus of the same general type as that described is being built by several other manufacturers. (See "Step Voltage Regulators," F. L. Snyder, *Electric Journal*, June 1934).

Under the heading "Determination of Size of Step," some statements are made and some conclusions reached which are not substantiated by other manufacturers' experience. It is stated, for example, in comparing the half-cycling and full-cycling principles of operation that "the smaller the step the smaller the voltage and kilovolt-amperes to be interrupted and the smaller the contact deterioration." Let us take 2 regulators of this same general type, the one having 32 steps with half-cycling operation and the other 16 steps with full-cycling operation, the voltage and kilovolt-amperes interrupted will be exactly the same for both regulators and therefore the contact deterioration will be the same per switch operation.

The statement is made that "It may be seen that for $1^1/_4$ per cent steps with full-cycling operation there are 2 circuit openings and 2 circuit closings for each tap change. The duty is just twice what it is for a regulator using half-cycling operation and giving $^5/_8$ per cent steps." Let us assume that the 2 regulators referred to above operate over a definite percentage of their range; each regulator will have made exactly the same number of contact openings and contact closings and will be subject to the same contact deterioration. The duty will therefore be the same on each regulator.

The statement is made that "the use of $^5/_8$ per cent steps is advantageous also because with the fluctuating voltages encountered in average regulator service, the smaller steps will result in fewer tap changing operations." In support of this statement the assumption is made that the relays on both regulators under discussion would have the same setting. This would not be the case in actual practice since it is is universally recognized that the relay on a step voltage regulator must not be set to operate at voltage variations less than the voltage correction made by one operation of the regulator, since to do so would obviously result in hunting. The relay on the full-cycling operating machine must therefore be set to operate when the voltage varies from normal by $1^1/_4$ per cent instead of 1 per cent as assumed. With this relay setting corrected, the full-cycling machine will make one tap change instead of 9 while the half-cycling machine will make 2 tap changes for the variation in impressed voltage shown in figure 6 of the paper.

Furthermore, it does not appear logical to assume that the voltage variation shown in figure 6 is typical. It would seem more reasonable to assume, as the load varies from light load to full load, that the regulator will move progressively over the larger part of its range. Under such conditions the half-cycling operating regulator would again make twice as many operations as the full-cycling operation regulator and 4 times as many as the regulator designed for $2^1/_2$ per cent steps.

There is no doubt but that the step type voltage regulator has certain very definite advantages over the induction regulator, particularly for application to the higher voltage and higher kilovolt-ampere 3 phase distribution circuits. The method of tap changing used in the regulator described by Hill is similar to that used by other manufacturers of the same type of apparatus, although the actual mechanical details of the regulator construction differ. Most manufacturers mount the tap changer and the core and coil assembly side by side in separate compartments in the same tank instead of mounting the transformer above the tap changer, as described by Hill.

The spring driven snap switch mechanism used for driving the tap changer, with a quick break action, is not necessary to interrupt the circuit in the first half cycle, since other manufacturers of the same type of equipment are able to interrupt the arc in the first half cycle with a positive and solidly connected mechanical drive without the use of springs. This construction may have the advantage that it eliminates the motor brake and the pilot motor holding-in switch.

The automatic and antihunting control referred to is the same control scheme that is used for the operation of automatic induction regulators with the exception that a time delay is introduced between the making of the primary and secondary relay contacts. This time delay eliminates needless tap changes due to voltage swings and is necessary because the step type regulator varies the voltage in a certain definite predetermined amount for each operation while an induction regulator stops as soon as the voltage has been returned to normal.

L. H. Hill: The discussion has indicated that the conclusions reached in my paper concerning the use of $^5/_8$ per cent steps versus $1^1/_4$ per cent steps are not justified by operating experience. I do not agree with this conclusion, because all of the regulators manufactured by the company which I represent are in operation with $^5/_8$ per cent steps, and by actual observation of their operation in the field it is possible to easily determine that one $^5/_8$ per cent step is sufficient to balance the contact making voltmeter in many cases. By actually observing the operation of a regulator it will be noted that if the unit makes only one $^5/_8$ per cent step to balance the relay, it must clearly indicate that the $^5/_8$ per cent step is sufficient to balance the relay; hence, a $1^1/_4$ per cent step would not have been necessary, and would simply have provided overcorrection. As F. L. Snyder has agreed in his discussion, a $1^1/_4$ per cent step with full-cycling operation is the equivalent of 2 $^5/_8$ per cent steps with half-cycling operation; hence, a $1^1/_4$ per cent step represents twice as much contact deterioration as a $^5/_8$ per cent step.

Snyder points out that for regulators to operate over a given range the duty on the contacts is the same with $^5/_8$ per cent half-cycling steps as compared with half as many $1^1/_4$ per cent full-cycling steps. There is, of course, no difference of opinion concerning this, but the point is the duty on the contacts even when operating over wide ranges shows no advantage for the larger size of step. Regulators, however, operate under fluctuating voltage conditions, and as outlined in the paper, this is the condition which results in fewer operations when smaller steps are used.

Snyder takes issue with the fact that a comparison was made with $1^1/_4$ per cent steps and $^5/_8$ per cent steps using the same relay setting of plus and minus 1 per cent. He points out that with $1^1/_4$ per cent steps the relay setting should not be as close as plus and minus 1 per cent. This, however, is a pure admission on his part that the regulator with $1^1/_4$ per cent steps should not be used to regulate as closely as one with $^5/_8$ steps. The regulator described in my paper was designed to operate with the same relay settings which have been used with induction regulators, and the analysis of the size of step was made on that basis. If $1^1/_4$ per cent steps had been used, as Snyder points out, it would be necessary to set the relay contacts farther apart, which would not give the results which can be obtained when $^5/_8$ steps are used. Of course the reference to $2^1/_2$ per cent steps resulting in fewer operations again presupposes setting the relay contacts farther apart than is required for the type of operating service the regulator is designed for, and has no bearing on the discussion concerning a regulator designed for close regulation.

As a matter of fact, it is difficult to reconcile the views expressed by Snyder in this discussion, because the company which he represents builds their regulator, which is advertised as $1^1/_4$ per cent steps, full-cycling

operation, so it can be arranged to stop on the half-cycling position and thus provide the $^5/_8$ per cent step under consideration.

To summarize concerning the size of steps, the regulator described in the paper is designed to operate with $^5/_8$ per cent steps, and the control is such that if one $^5/_8$ per cent step is not sufficient to balance the relay, it will automatically make another step. It should be evident that this arrangement cannot help but result in fewer total operations, especially considering that the $1^1/_4$ per cent step is really equivalent to 2 $^5/_8$ per cent steps as outlined above.

It might be pointed out that the reason for mounting tap changer and transformers above one another instead of side by side is to reduce the floor space. The step regulators under consideration are designed to go into vaults used by induction regulators which would not be possible with any other arrangement.

The use of the quick-break mechanism is not because of necessity but rather because of superior features obtainable by its use. Tests on contacts to measure contact deterioration indicate definitely the much longer life obtainable by its use. The use of a quick-break mechanism as described, however, eliminates the need for a brake on the driving motor, with attendant maintenance.

The time delay in the control is not necessary because the step voltage regulator varies a definite predetermined amount but is used to avoid unnecessary operations resulting from voltage changes of short duration where a regulator operation is not required and where a regulator operation would often make service worse than before. Induction regulator operation would be improved if time delay were provided in its control. This has actually been done in some cases.

Regulation Beyond the Distribution Substation

Discussion and author's closure of a paper by P. E. Benner presented for oral discussion at the distribution and transmission session of the South West District meeting, Oklahoma City, Okla., April 26, 1935, and published in the August 1935 issue, pages 832–7.

V. C. Gillon (nonmember; Oklahoma Gas and Electric Co., Oklahoma City): Certainly this paper is indeed most appropriate at a time when capital expenditures for power generation and transmission systems are small and the expenditures for distribution systems relatively large. This condition, brought about by low industrial loads but continually increasing residential loads, has diverted more and more administrative and technical engineering thought to the distribution system.

In the paper it seems that the curves, figures 2 and 3, where the per cent voltage drop is plotted against the per cent rate at which the investment in primary and secondary system changes, would permit the economic solution to be determined only if the total annual charges had been plotted as the ordinate rather than investment.

One thought in connection with the application of the secondary autotransformer is that a regular 5 kva transformer can be added at a cost of approximately \$110. The autotransformer costs approximately \$35 for 2 kva. It is evident that 5 kva additional transformer capacity can be added for \$75, or \$15 per kilovolt-ampere, which is very reasonable indeed.

The economic importance of electrical losses has become of lesser consequence over the past number of years as continually decreasing production costs in the power plants have contributed to this pronounced trend. The low costs of losses provide opportunity for economical application of supplementary regulating devices which would not have been advisable a few years ago. However, the determination of the cost of losses does not simply involve the average cost of fuel per kilowatt-hour. A more thorough analysis of over-all energy cost to the company should be made; at times it may be that fixed charges on a portion of the transmission and generation investment should properly be a portion of the costs of losses, as well as fuel costs.

The author has discussed the problem of instantaneous regulation causing light flicker and various proposed solutions. The following discussion will present an attack upon the problem of what constitutes objectionable light flicker caused by starting of single phase air conditioning motors in residential areas.

Regardless of the rate of growth of residential air conditioning load or the ultimate customer saturation and load density created by it upon the electric service company's distribution system, there is a problem of economically providing facilities to prevent objectionable light flicker caused by these units on single phase lines. What limit should be placed upon the voltage drop produced by starting of a motor has been a matter of great divergence of opinion among public service company men and considerable discussion has been accorded this subject by an Edison Electric Institute committee, by which some valuable data have been contributed.

It has been generally agreed that objectionable light flicker is dependent upon both the magnitude and frequency of occurrence of the voltage change. Those in the business are entirely too conscious and critical of the service to be competent to determine from their own personal reaction just what flicker is objectionable. To most of us almost any apparent flicker is objectionable, though an average customer will likely never even be conscious of these voltage dips.

Proposals have been made by some of those concerned with this problem to have doctors, psychologists, and optometrists consulted in order to determine just what flicker is objectionable. We decided to impose conditions of light flicker upon groups of average customers, without their knowledge, in order to determine what flicker would cause them to complain.

An air conditioning compressor driven by a 240 volt, 3 horsepower, single phase repulsion-induction motor as a flicker producer was used. This machine was equipped with a time clock controlled line contact so that it could be left unattended and set to start up at certain fixed and regular intervals. An actual air conditioning unit was used because it was desired to simulate the flicker of an actual installation; that is, a unit which had the same current-time characteristics upon starting. The time intervals or frequency of starting of the unit were set at 20 minutes. The length of this interval was determined by the study of charts which were taken from 14 actual residential installations during the 1934 season.

During the high temperature days, the air conditioning units run continuously, though on cooler evenings, when residential customers are using lighting for reading, the units do not run continuously, but start up about every 20 minutes and run for a short time. The data taken on residential air conditioning installations indicate that the machines are not usually operated under fully automatic control except on very hot days when the units run continuously. On cool evenings, when the automatic control would cause the machine to start up most frequently, the customers usually shut the machine down with the manual control switch and, therefore, it is seldom that the machines start up more than a very few times a day.

This test machine was located in a company employee's garage in a good residential area; that is, a section of reasonably prosperous customers where there may be some future hope of having air conditioning installations. These residences also have lighting which corresponds to that in the more prosperous homes.

The machine was adjusted to start up every 20 minutes, each evening from 6:00 p.m. to 12:00 p.m. for a period of 3 weeks. It can be readily seen that a machine starting at such frequent intervals every day gives a very much accelerated test in comparison with permanent residential installations.

At one location a drop of 9.5 volts was produced on the 120 volt lighting circuits and affected thus the service of 7 customers for 21 consecutive nights. The load was supplied by 500 feet of No. 2 secondary wire on cross arm construction, and a 25 kva transformer. None of the customers whose service was affected by the starting of the unit registered a complaint with the company. Interviews with these customers revealed that they had not noticed any disturbance or unsatisfactory electric service, even though leading questions were asked them, such as to the flicker of their lights. One customer had been bothered by the noise of the motor upon starting but did not complain.

The flicker machine was moved to another residential location where a voltage drop of 10 volts was produced by starting of the motor and affected the service of 9 customers for a period of nearly 3 weeks.

In this latter area one customer complaint was received by the company. It was learned that this customer occupied a back bedroom in a house just behind the garage in which the flicker machine was located, and that the customer habitually read in bed late at night. The customer reported that the lights dimmed and that there was a loud buzzing noise in the alley. This customer seemed to be as much or more interested in eliminating the noise as in the light flicker, thinking perhaps that the noise indicated something wrong with the company's facilities and that we would like to know it.

Interviews with other customers in this area revealed that 2 of them had noticed the light flicker but they did not consider it sufficiently objectionable to justify their complaining to the company. The remainder of the customers in the area had not even noticed any light flicker.

Throughout the 1934 air conditioning season, data as to voltage drop and current upon starting of the units were accumulated, the summary of which is given here for several residential installations.

Rating of Motor: Horsepower	Rating of Motor: Volts	Volts Drop on Lighting Circuit	Number of Customers Affected
1	110	13.5	4
3	220	8.0	4
3	220	7.1	8
$1^1/_2$	220	4.5	4
1	220	5.0	12
$1^1/_2$	220	7.5	2

All of these installations were operated during the 1934 season and there were no customer complaints as to unsatisfactory voltage conditions or light flicker received. These data were taken under typical conditions as they do and will exist upon the system in residential areas and yet no customer complaints were registered even under some rather extreme conditions of voltage drop.

It is believed these tests and experiences may indicate that an 8 per cent drop upon starting of an air conditioning unit is noticeable, but not seriously objectionable and may not cause the customers to complain. In the case of more frequent starting, however, such as elevators, this value must be much lower. Of course, there will be a few customer complaints from customers in the category of perpetual complainers but such exceptional cases can be remedied and the system economically designed for average conditions. These remarks should not be construed as meaning that the necessity for limiting starting currents of motors upon distribution systems is to be minimized.

John Oram (Dallas Power and Light Co., Dallas, Texas): Where it can be clearly shown by economic analysis that voltage regulation and not excessive energy loss is the limiting factor, supplementary regulating devices appear to have a particular field of application. This condition is closely associated with load factor or hours use of lines and equipment, type of service rendered, and other considerations, and therefore no general rules can be formulated to cover all conditions.

It seems fairly obvious that under conditions of low load factor and long branch circuits, or where the voltage supplied to such branch circuits is subject to wide fluctuations, a special voltage regulating device would be a reasonable solution.

There is danger, however, of going to the extreme of spending too much money for regulating voltage within narrow limits, especially in certain outlying and poor revenue producing sections.

It is my feeling that further research might be properly directed toward producing a type of lamp having less critical characteristics as to voltage and lumen output; in other words, less sensitive to voltage variation than the present types.

C. I. Hendricks (Texas Electric Service Co., Fort Worth): The paper describes means of mitigating voltage regulation difficulties an overhead distribution systems, the result of justified procrastination following our economic instability period of the past 5 years. Although there is no doubt but that we should correct regulation difficulties that now confront us, it would be wise not to overlook the paramount fact that our distribution systems should be so designed as to provide adequately for the domestic load increase incurred during the past 5 years and which, in all probability, will continue in the future. This thought can be accentuated by mentally visualizing the importance placed on domestic service continuity necessitated by the ever increasing use of domestic appliances.

The author very ably points out regulation limits for a well designed overhead distribution system and, also, describes unique means of arriving at the economic allocation of voltage drop throughout the distribution system. He then discusses methods of remedying incorrect voltage situations on a limited economic basis.

Undoubtedly economic reasons may, in many prevailing instances, dictate mitigation means of regulation correction; however, we should again stress, at the expense of repetition, the thought that a distribution system, embodying simplicity in design and having low inherent regulation qualities, will provide the most reliable service at a minimum operating cost.

The company with which I am affiliated has, to a limited degree, utilized autotransformers as a means of alleviating voltage dips on overhead secondary conductors caused by the starting currents of 120 volt fractional horsepower motors. However, the use of autotransformers should not be considered a panacea for all such instances. A careful diagnosis of certain cases reveals the fact that the application of an autotransformer can, regardless of capacity, be of little or no practical value in minimizing the voltage drop.

With the author's paper as a guide, calculations field tests to check them have been made in an endeavor to determine the efficacy of autotransformers as a means of alleviating voltage dips caused by starting currents of fractional horsepower 120 volt motors connected to overhead secondary lines. The results obtained were, in general, similar to those given by the author and, although time did not permit such a thorough study as reflected in the paper, the conclusions reached are accurate within reasonable limits.

In figure 10*B* of the paper it is shown that a standard 5 kva distribution transformer can satisfactorily be used with prescribed load requirements and voltage drop limits. The calculations and tests referred to clearly indicate that a standard 5 kva 4,000/119 volt distribution transformer, having a ratio of reactance to resistance of 1.16, will not be applicable when circuit voltage, power factor, and current characteristics are used as assumed by the author in figure 10*B*.

It is altogether possible that the author has considered a more recent design of distribution transformer; however, since relatively few distribution transformers have been purchased during the past 5 years, our problem, to a large measure, involves transformers of a vintage prior to 1930. Further calculations of conditions similar to those assumed by the author in figure 10*B*, produced results that permitted the use of autotransformers having lower kilovolt-ampere ratings than those illustrated by the curves in the figure.

It is concluded that, before the practice of autotransformers be adopted as a means of alleviating voltage dips on secondary lines, a careful analysis should be made, taking into consideration all pertinent operating factors such as resistance of conductor connections, relative drop through distribution transformer when using half of the secondary winding, power factor of increment current during peak and light load periods, actual conductor spacing, and other aspects.

In short, probably the practice of using autotransformers as a means to correct undesirable voltage situations is merely an expedient, unless this practice has first been economically justified for the distribution system under consideration.

P. E. Benner: Reduction in distribution system investment by the installation of supplementary regulating devices is most apt to obtain in fringe areas which are only partly built up, or in places where physical limitations prohibit the use of the regular type of construction. One especially attractive feature of the supplementary regulating device is its mobility. Transient conditions of load growth in fringe areas may require the installation of a pole type regulating device or an autotransformer in one location one year and in some other location a few years later.

Careful thought should be given to the idea that areas of low load density do not justify good regulation. This idea probably originated when rendering good service from the standpoint of voltage regulation required large investments in extensive primary facilities, but certainly should be reconsidered now in the light of the newly developed low-capacity low-cost regulating devices. Another phase of this same subject is the effect of good regulation on revenue, and it is believed that a conservative evaluation of this factor will often remove any doubt as to the desirability of improving voltage conditions.

As V. C. Gillon suggests, a rigorous solution of the problem of proportioning the voltage drop between primary and secondary circuits would be based on annual charges rather than investment. Realizing, however, that major parts of the annual charges of primary and secondary systems are a function of their respective investments, it was believed advisable to make this approximation for the sake of simplification. The tests described by him are very interesting and these and other similar tests might very well form the basis for establishing a practice regarding the permissible voltage fluctuations resulting from the installation of air conditioning equipment. Care must be taken, however, not to confuse the relatively infrequent voltage fluctuations caused by air conditioning

equipment with those caused by domestic refrigerators. The more frequent starting of the latter would necessarily limit voltage fluctuations caused by them to a much lower value than the 8 per cent suggested by Gillon.

The curves, figure 8, which show the application of auto transformers for reducing light flicker are based on the design of 2,400-240/120 volt distribution transformers which has been more or less standard for a number of years. Actual tests made on a stock 5 kva transformer gave the following results:

Per cent resistance and reactance of the transformer with both low voltage windings loaded to rated capacity and on a 5 kva base.................. 2.12 per cent and 1.68 per cent, respectively.

Per cent resistance and reactance of transformer with one low voltage winding loaded to rated capacity and on a $2^1/_2$ kva base.................. 1.66 per cent and 1.13 per cent, respectively.

The starting current considered was for a motor connected line-to-neutral so in figuring the transformer drop the resistance and reactance values with one low voltage winding loaded to rated capacity and on a $2^1/_2$ kva base were used.

The calculated drop through the transformer from the 25 ampere, 0.5 power factor starting current was 2.6 volts. The voltage drop in approximately 35 feet of No. 4 secondary wire would bring this up to 3 volts, which was the assumed limit.

The situation to which the curves of figure 8 apply is probably somewhat pessimistic in that a 25 ampere, 0.5 power factor starting current is larger than that generally encountered. Permissible secondary runs for other currents of the same power factor can be estimated, however, with the additional information that a 25 ampere, 0.5 power factor current has approximately 3 volts drop in 265 feet of No. 4 secondary. Using this figure, it can be readily determined that a $12^1/_2$ ampere, 0.5 power factor starting current will cause a 3 volt drop through a 5 kva distribution transformer and 300 feet of No. 4 secondary.

Design and Operation of Huntley Station No. 2

Discussion of paper by H. M. Cushing published in the June 1935 issue, pages 632–45, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935.

C. M. Gilt (Brooklyn Edison Co., Brooklyn, N. Y.): The engineers who designed the Huntley Station No. 2 had the good fortune of being able to make a combined design of distribution system and generating station without having to adapt the station to an existing distribution system. In so doing they were among the first to take advantage of the 2-winding principle which has been used in both generators and transformers. By means of this, circuit breaker current capacities and interrupting ratings are reduced, the need for bus reactors is eliminated or greatly reduced, the reactance between bus sections is high while the normal through reactance from generator to load is kept low. Associated with these advantages are 2 disadvantages, one of which is the fact that there is no independent control of voltage and phase angle of the 2 windings with the result that unequal loadings result in unequal voltages and phase angle differences between bus sections. It is especially important that voltage and phase angle differences be kept small when a low voltage network is fed directly from the generating station busses without intervening feeder regulation. Comparatively small phase angle differences may trip open and cause frequent operation of sensitive network switches on lightly loaded transformers or cause overloads on heavily loaded transformers. The other disadvantage resulting from the 2 winding designs is the impracticability of transferring load from one bus section to another through the transformer (or generator) tying the bus sections together. This condition may result in real loss in station economy if it requires operating units with loadings that differ materially from those giving maximum station economy.

These limitations have apparently been completely met in the Huntley Station design by the use of 2 feeder breakers per feeder and the ability to adjust the number of feeders on each bus to secure equal loadings. Large bulk power feeders automatically aid in balancing the load on the 2 windings of the generator transformers by means of the 2 primary windings of the feeder transformers, one of which apparently is connected to each of the busses. One or 2 generators can be operated and the load divided between them for maximum station economy by transferring load across the bus tie breakers, which the diagram indicates normally are operated closed.

While such complete flexibility in load adjustment is convenient, the experience of the Brooklyn Edison Company indicates that for its conditions it is not necessary, and no doubt the choice of 2 breakers per feeder was determined by other factors. It has been possible in Brooklyn to obtain adequate load balancing and adjustment between generators by connecting groups of 4 or 8 feeders to one generator or another, with some load transfer across the synchronizing bus to which all generators are connected through reactors. It is, of course, necessary to connect feeder cables to switch positions in such a way that reasonable load balance is maintained on the various feeder group busses. By this means it has been possible to operate so that the voltage difference between the windings of the 2 winding generator autotransformers does not exceed and is usually less than 2 volts, on the basis of 120 volts delivered, or 1 volt above and below the objective mean.

Feeder groups are connected to machines in such a way that it is possible to obtain the desired machine loadings for economy without exceeding phase angle differences between busses of greater than about one degree. These are generally practicable working conditions for network supply.

I am not a little surprised at the experiences described while the 22 kv system was operated solidly grounded, during which time cables which failed sometimes blew themselves clear of the failure without tripping the station breaker, sometimes leaving exposed live conductors. The Brooklyn Edison Company has operated a solidly grounded 27 kv cable system since 1923 on which feeder short circuit magnitudes are usually of the order of 300,000 to 400,000-kva, 3-phase value. So far as we can recall, there has been but one similar case. Upon investigation of a manhole that had been reported to have exploded, it was found that a 3-conductor, 27-kv cable joint had blown open and the arc extinguished itself without tripping the station breaker. The cable was taken out of service before the open joint broke down again.

M. Penn (Public Serv. Elec. and Gas Co., Newark, N. J.): From H. M. Cushing's, paper it is evident that the unusual conditions under which the plant would be operated were well understood in advance and the operating results show that these requirements were capably provided for. An outstanding part of the paper is the thorough analysis and codification of the requirements which the station must fulfill. The importance of clearly defining the problem and the objectives of any engineering project before designs are drawn cannot be over emphasized, though the task may sometimes be rather difficult and require considerable time. In this way all concerned with the design may work toward a common purpose.

This station while intended for low capacity factor operation seems to be a very complete 400 pound plant as far as heat saving and control equipment are concerned. The design, however, was intended to permit a low installation cost per kilowatt of capacity with low operating and maintenance costs. At the same time reliability and rapid response to load changes were primary considerations. The paper indicates to some extent the degree to which these objectives were accomplished, although whether or not low installation cost per kilowatt of capacity was obtained and low operating labor and maintenance costs as well, are not stated. This information would be very useful in order to determine whether a plant intended for low capacity factor operation and utilizing moderate steam pressure and temperature could be built and operated at any considerable saving over a high pressure and high temperature base load plant.

The tabulation of over-all operating performance indicates that very good fuel economy has been obtained for operation at low capacity factors. In 1933 and 1934 the annual heat rates are given as less than 14,500 Btu per net kilowatt-hour with capacity factors of 25.8 and 22.5 per cent. Table I shows that during these years the 80,000 kw generating units operated 15 per cent of the service hours at between 5,000 and 10,000 kw load and 42 per cent of the time in service at loads of 20,000 kw or less. Loads up to 90,000 kw were carried for short periods.

It is stated that 4 tons of coal per 24 hours are required to keep a 560,000 pound per hour pulverized fuel fired boiler within 100 pounds of line pressure. Low banking fuel consumption probably accounts to some extent for the low average heat rate of the station at low capacity factors.

The use of slag tap furnaces with boilers operating at such low average ratings seems unusual. The special igniting oil burners for starting pulverized fuel boilers is also a feature worth noting.

If the stacks at Huntley are steel as appears to be indicated, are they fully lined, or what provision has been made to prevent corrosion? At Kearny and Essex generating stations considerable corrosion of several lined steel stacks was recently discovered.

The operating record shown in table I does not indicate very high availability of main units although it is stated that turbines are not taken out for overhauling oftener than once in 2 or 3 years. The average unavailability for units 1 and 2 for 1933–34 was 19 per cent. Table I has a typographical error in the column "Hours Idle But Available" where the figures for No. 2 unit in 1932 and No. 1 unit in 1933 are interchanged.

The data given on starting time for these large units emphasize the value of the motor-operated turning devices to keep the turbine rotors straight, while the rapid increase of load under test shows the possibilities in an emergency.

The use of generators without direct connected exciters is somewhat unusual. Perhaps Mr. Cushing will give the reasons for the choice.

The most interesting item in the electrical layout is the application of the split bus scheme. This is an objective toward which we aim in the ultimate development of our 132 kv loop although we do not operate that way at present. In 1927 and 1928, Public Service Electric and Gas Company of New Jersey made a careful study of its 132 kv transmission network and carried these studies forward to a system capacity of 2,000 megawatts. The purpose was to determine a system of transmission which could be almost indefinitely developed without obtaining excessive short circuit currents or such severe disturbances to the system with 132 kv faults as to cause the system to pull apart, either within itself or from neighboring systems to which it might be tied. Provision was made for the adoption of a double bus system in which busses and bus sections could be tied together by utilizing the split windings of the connected transformers. In 1929, a 90,000 kva bank of transformer incorporating these features was purchased for Roseland switching station which serves to step down the voltage from 220 kv to 132 kv. The through reactance from primary to secondary was specified as $13^1/_2$ per cent, while the transfer reactance between 132 kv busses was specified as 114 per cent. We should like to learn from Mr. Cushing if the aim of balanced loads on both sides of the transformer was difficult to achieve in practice and, when unbalances do occur, what is their magnitude and effect. Also, how far is the split nullified by the cross connections between the 2 busses which occur in the subtransmission network. Another point is that this scheme of short circuit protection places a definite limit on the transmission layout, since any substation high tension busses fed from different bus sections would short circuit the protective feature.

It would be interesting to find out if the practice of grounding through a 5 ohm resistor has, in the operation of this system, brought forth any data on overvoltages under single line to ground fault conditions or if any low frequency induction with the communication companies has been experienced.

The use of simple conventional types of switching equipment of modern design was certainly sound engineering in this case. In many instances a conventional masonry bus and switch structure, using modern equipment, will not only have practically all of the essential advantages of unconventional switchgear, but will be more adaptable to local conditions, more flexible for future requirements, and more economical, particularly for the main switching connections of a large generating station.

It would be interesting to learn more of the details of the very fast clearing of faults on the 22 kv cables when operating dead-grounded, as usually with a dead-grounded system, the fault current is severe and holds on until the protective relays function.

The designers of this station were very fortunate in not being handicapped by a large number of conditions which more or less dictate the detail design of the station. The 7 months' operation at a net heat rate of 13,812 Btu per kilowatt-hour shows that details relating to economy have been watched with care. This, plus the splendid operation under emergency conditions and the quick, economical methods of handling repairs to auxiliaries by means of monorails and hoists all reflect credit on the designers for having developed a layout which so admirably meets the requirements.

F. A. Allner (Pa. Water and Pwr. Co., Baltimore, Md.): H. M. Cushing's paper is commendable for its excellent analysis of the design of the power plant discussed; it is distinctly more than a description of another plant. In addition, for the benefit of power plant engineers at large, Mr. Cushing has laid bare with generous frankness such shortcomings as experience in operation have revealed.

The principles of plant design exemplified by Huntley Station No. 2 are of vital interest at the present time when power engineers are directing their thought to the supply of the increased load demands that appear imminent. Naturally the extension or rehabilitation of existing stations is given first consideration when the trend of the load curve indicates that additional capacity may be required, but in any sustained upward swing of the load a time soon comes when a major addition in the form of a new plant becomes necessary. Huntley No. 2 presents an alternative scheme of design to that apparently being given wide study and consideration during the past 4 or 5 years, i. e., high pressure and high temperature.

The steam pressure and temperature at the turbine throttle in Huntley No. 2 appear to be 425 pounds and 750 degrees, or what may be said to be low pressure and medium temperature when compared to the maximum conditions discussed for modern plants. However, the plant should be judged in the light of the economic results secured by it. Figure 12 shows a possible best heat rate of 12,300 Btu per net kilowatt-hour, and table II shows actual heat rates under load conditions that require a great number of starts of boilers and turbines and a large proportion of boiler banking hours. Certainly the thermal results secured under the existing conditions of load and what appears to be not the highest grade of coal, approach the best fuel economy so far reported for any steam-electric station. Moreover these thermal results are obtained by a plant which appears to have a somewhat unusually low cost per kilowatt of installed capacity. If the data in the paper about building and construction costs are correctly interpreted, the cost per kilowatt seems to be about halfway between the figures often quoted for total plant and incremental capacity costs. The paper therefore squarely raises the question of whether or not plant designers have overlooked the potentialities of existing design schemes in their efforts toward greater economy through the use of super pressures and temperatures. Is it possible that the depature from low to medium steam conditions is predicated upon the supposition that other elements of plant design are fixed or that their possibilities have been exhausted?

The paper does not indicate that the inherent quality of the design was due to the absence of any handicap of having to fit the station into an existing system, although upon first thought this might seem to be implied under the heading "Design Requirements." It is difficult to imagine how external matters could have seriously circumscribed the features which seem to have contributed largely to the general excellence of the design. Rather one gathers the impression from reading the paper that the points of novel merit in the design came about solely from judicious selection and arrangement of equipment and from a clear distinction between essentials and non-essentials.

At the risk of repetition of the contents of the paper, the features of design which reveal an independence of thought and which undoubtedly contributed to the low cost of the station, appear to be as follows:

1. A very compact switchhouse which in comparison with many others is remarkable for its simplicity and small volume.
2. A centralized location for the house service transformers and buses.
3. A compact boiler house of minimum height and containing large air heaters of minimum volume.
4. An almost vertical draft system.
5. An accessible boiler setting without economizers that is supported at the bottom instead of being hung from a structural framework.
6. A stack temperature of less than 300 degrees at full boiler load.
7. Absence of interior coal bunkers and coal elevating equipment.
8. Outdoor coal storage lot that also serves as a boiler bunker.

The design of the switchhouse and switching equipment merits close attention.

Turning to the matter of co-ordinating the design of the plant for use on a power system that is predominantly hydroelectric, it is noted that Mr. Cushing has listed "rapid response to sudden changes in load" initially in the design requirements, and elsewhere in the paper he has described speed-of-response tests with turbines and boilers. Quick response of equipment already in operation either floating or carrying minimum load is to be distinguished in this connection from the ability to start turbines quickly from standstill and boilers from a cold or banked condition, together with the related matter of economy of starting and stopping equipment. The first aspect of operation is essentially an emergency condition, and may occur with either steam of hydroelectric plants; the second is associated with the peak operation of either type

of generating plant. Hydroelectric units, of course, are almost ideally suited for quick starting from standstill, and in certain instances already described to the Institute they can be started and synchronized sufficiently quickly to avert serious consequences in the event of the emergency loss of other units on the system. Likewise when hydroelectric units are used for peak operation, the starting and stopping and equivalent banking losses are practically nil.

The load curves shown by Mr. Cushing indicate that the Huntley Station No. 2 is never shut down completely. When other plants on the system are available to carry the entire 24 hour load, the plant is operated at minimum load of 5,000 kw on one turbine and one boiler, with 2 other boilers in hot reserve. This is evidently operation for system protection in emergency, to facilitate which certain signaling and furnace lighting equipment were provided. Facilities of this nature are installed in most stations, and their addition would not modify the basic design of the plant.

On the other hand, when the plant is used for peak operation as shown by 2 of the typical load curves, load is nevertheless carried during the valley periods. The plant in consequence is not subject to the type of operation that may occur with steam relay plants when the hydro capacity in periods of plentiful water is greater than the valley load. On such systems the economy of boiler banking and of starting and stopping turbines and boilers is an item to be considered in the design of a steam relay plant. Mr. Cushing has provided a turning device on the turbines in order to minimize the starting period, really for the purpose of economy in starting since steam turbines have no value for instant starting in emergencies. Turning devices are also in common practice.

It, therefore, seems that the design of the plant was not prejudiced or modified in any material respect for the purpose of coordinating its operation with that of the hydroelectric plants on the system, nor even for the sake of rapid response to sudden changes in load. Any opinions that Mr. Cushing may have about the disadvantages of steam cycles and conditions different from those that were adopted may only be surmised from his paper, but it is likely that he would have objections to them also on the ground of their cost as compared to that of the scheme adopted.

One is led to wonder after reading the paper why the plant cannot be shut down entirely during load valley periods, and why it is necessary to keep 2 boilers in hot reserve for which 4 tons of coal are necessary per boiler per day. The furnace and boiler design and the system of combustion would appear to be favorable for quick starting from a cold or banked condition. Data of the time necessary to start a cold boiler and the fuel requirement for starting would be of interest in this connection. Also, it would be of interest to know, if the number of boiler starts shown in table II includes the lighting of burners for the purpose of holding reserve boilers within 100 pounds of line pressure.

The impression obtained from reading the paper is that the new 60 cycle system replaces in large measure the 25 cycle system in Buffalo, which had been served by an adjacent steam-electric plant of 305,000 kw capacity. Mr. Cushing does not mention whether or not the possibility of the rehabilitation of the 25 cycle station was considered in connection with the selection of a site.

F. R. Longley (Western Mass. Companies, Springfield): One of the most striking features of the plant, as described under the subheading "Electrical Connections," is the limitation of bus faults by means of the split winding transformers. If conventional reactors were used to give the through reactance of 5.46 per cent, the transfer reactance would be only 21.84 per cent as compared with the 50.4 per cent, which is obtained from the split winding autotransformers by means of the mutual magnetic coupling between windings.

It is well to bear in mind that the reactance obtained from split winding transformers is entirely different from and more advantageous than that provided by reactors.

It is stated in the paper that the voltage on the unfaulted bus section actually tends to rise; and that with the station extended to 600,000 kva in generating capacity, and 360,000 kva of 110 kv transformer capacity, the use of split winding transformers will limit the bus fault to 715,000 kva. It would be interesting to know the magnitude of this fault if split winding transformers were not used. The autotransformer capacity and the 110 kv transformer capacity connected to the 22 kv bus would total 960,000 kva. The bus fault, if split winding transformers were not used, could be several times this connected capacity, or several million kilovoltamperes.

Considering the reduction in short circuit current thus obtained without impairing the operating performance of the station, it would seem well for those of us who are planning future generating stations to give careful consideration to the use of split winding transformers and generators.

The single line diagram in figure 9 shows a large number of 22 kv switches normally open, any one of which if unintentionally closed would tie the 2 bus sections solidly together. Is there any arrangement such as interlocks to prevent such unintentional operation?

Under the subheading "Fault Protection" is a description of 22 kv cables burning themselves clear during faults in less than 3 cycles, when the system neutral was solidly grounded. This performance is indeed surprising. If it can be depended upon to repeat it may offer some possibilities for clearing faults that occur in manholes and vaults. Will the author elaborate on this, giving a description of the cable used at the points of fault and including copper size, insulating material and the thickness of insulation? What was the magnitude of the total fault current and the branch fault currents fed in from each of the 2 sides of the fault? Was the conductor burned in two or was the sheath and insulation merely stripped away leaving the conductor continuous?

Since the Huntley Station No. 2 was designed and built, further progress has been made in the use of high steam pressures, such as 1,200 pounds; the use of the mercury vapor steam cycle; and the location of station equipment out of doors.

For the information of engineers who are considering the construction of new steam plants, what part, if any, of these advanced features would the author incorporate in the design of the Huntley Station No. 2 if it were being designed today; and what part, if any, would he incorporate in the design of an equal size base load steam plant?

E. G. Bailey (nonmember; Babcock and Wilcox Co., New York, N. Y.): H. M. Cushing has described and given operating results showing the basic reliability and the economy of a power generating station which was well designed to serve as a backlog of reliability for the system. Mr. Cushing and his associates deserve a great deal of credit for initiating and working out details regarding coal handling and storage, pulverizers, feeders, lighting torches, burners, and slag tap furnaces.

The coal handling equipment deserves special consideration. In stand-by plants, where large quantities of coal are stored in overhead bunkers, the problem of spontaneous combustion is always present. This has been avoided by having the storage all out in a pile where it could easily be moved in case of spontaneous combustion, and with no coal, either raw or pulverized, in overhead bins.

The automatic oil lighting torches developed in this station have proved to be a very useful adjunct to a stand-by plant where frequent lightning up and quick response are so important. Such torches are also useful in every pulverized coal installation.

In designing fuel burning and steam generating equipment the problem of efficiency is divided between the combustion of fuel and the absorption of heat. Efficiency in the absorption of heat depends primarily upon the amount of heat absorbing surface one wishes to buy, the amount of which should be a function of the load factor and the fuel cost. Mr. Cushing has obtained adequate efficiency for his load conditions from the absorption of heat, while in the burning of fuel and development of heat he has put in a very efficient plant. The difference in cost between a plant designed for high combustion efficiency and one for moderate or low efficiency is so little that one can never afford to do otherwise than install a plant with good fuel burning efficiency, even with a low load factor. Mr. Cushing has built a low cost plant, but not a cheap plant.

Papers of this kind, written after sufficient period of normal operation, together with tests and operating data, are an invaluable aid to power station designing engineers and equipment manufacturers.

Huntley Station No. 1 was the scene of developing the first slag tap pulverized coal fired furnaces, and the soundness of the principle is evidenced by 80 or more furnaces of this type now being in successful operation. While the author mentioned 2,500 degrees fusing temperature as the upper limit, there are other stations that are successfully handling a somewhat higher fusing temperature. The development of the slag tap furnace has opened up entirely new possibilities in the use of low grade coals, and in the size and design of boiler units.

When the first pulverized coal unit for

Huntley No. 1 was selected 10 years ago, the list of pulverized coal fired plants of any kind were few, and the question of direct firing versus bin system was much debated. Space limitation was an important factor in the earlier installations, but direct firing proved so satisfactory that Huntley No. 2 also used direct firing, as have many other important stations.

Later experience has shown that direct firing has a definite advantage over storage systems in lower carbon loss. With a bin system, particles of coal become packed together, and when fed to the furnace are equivalent to coarser coal than the mill actually produced. This results in a greater carbon loss than prevails in direct firing, with proper pulverization, where each particle of coal is carried separately in the primary air.

The author brings out the question of rapid response of the coal burning equipment and shows that the unavoidable swell of the water in the boiler, due to increased rate of steam generation, limits the rate of load pickup. This problem is being studied more thoroughly, and further improvements can be obtained where conditions warrant.

Since this station was designed 5 years ago further improvements have been made in the reliability of fuel burning and steam generating equipment so that a spare boiler might or might not be needed, depending upon local conditions.

H. C. Albrecht (Phila. Elec. Co., Pa.): The Institute is fortunate in that this paper not only gives the design requirements of this plant and details of how these were met, but also includes results of operating experience for 4 years.

While the advantages of location of this new 60 cycle station adjacent to the existing 305,000 kw, 25 cycle station are listed, no mention is made of the possible disadvantages, from the standpoint of both generation and transmission, of concentrating all steam generation at one point for a system of the ultimate capacity planned.

It would also be interesting to know something of the future plans for the 25 cycle capacity and whether changeover to 60 cycles is contemplated.

It is rather surprising to note that the 80,000 kw generators do not include direct connected exciters. Their advantages have been generally recognized, and on the Philadelphia Electric system experience has been most satisfactory for over 20 years.

The statement is made that the turbine bay with a 100 foot span is designed to accommodate future units up to 200,000 kva tandem type. At Richmond station we are just completing the installation of a 165,000 kw, 183,333 kva tandem unit in a turbine bay with a span of 120 feet and were only able to get it in crosswise by being able to handle the generator rotor through an opening in the building wall into a court between the turbine and electrical bays.

The use of autotransformers rather than higher voltage generators is noted and it would be interesting to know where they are located.

In the supply of auxiliary service from the generator terminals, 2 transformers are used, protected by oil circuit breakers. When installing the 2 60,000 kw units at Richmond station in 1925, we recognized the advantages of supply of essential auxiliaries from generator leads, but also felt it very desirable from a cost and reliability standpoint to make this connection as short as possible. Therefore a single transformer bank was installed directly under the generator leads, eliminating oil circuit breakers and disconnecting switches. Reserve supply is obtained from station busses or an emergency house generator.

The statement that a thorough study of the proper voltage for auxiliary motors showed that a single 550 volt system had decided advantages over other voltages is most surprising. Our studies on the Philadelphia system have indicated that supply of motors over 25 horsepower at 2,300 volts and smaller motors at 220 volts has decided economic advantages, and experience of over 15 years has indicated high reliability. Advantage has been taken of full voltage starting on 2,300 volt constant speed motors.

For the 165,000 kw installation at Richmond now being made, hydraulic couplings are being used on condensate pump, and forced and induced draft fan drive, eliminating resistors and contactors.

D. F. Pennell (nonmember; Brooklyn Edison Co., Brooklyn, N. Y.): Some phases of mechanical design of Huntley Station No. 2 are similar to the lines used in Brooklyn at Hudson Avenue. Large generating units (80,000 kw) were installed and moderately high steam pressures and temperatures were used. The station uses all a-c auxiliary power with no house generators. Provision is made for an emergency supply of a-c power from the Niagara-Hudson system.

The effect of the depression is illustrated here somewhat, as in the revamping of Connors Creek, by a willingness on the part of the designer to take advantage of economies which might have been disregarded in other years. For example, one of the advantages given for placing Huntley No. 2 next to Huntley No. 1 was that economies would result from common use of equipment already installed, such as coal handling equipment, machine shop, first aid rooms. In addition, operating economies were anticipated through co-ordinated supervision and the possibility of a free interchange of operating labor between the 2 stations.

The most interesting point in this paper is the way in which the design has been made to fit the very unusual load conditions under which the station operates. The station with 160,000 kw installed may be called upon to operate a full capacity for prolonged periods or to float on the line due to the fact that it acts as stand-by for hydro stations. Its capacity factors are of interest:

Year	Capacity Factor
1931	8.1
1932	5.7
1933	25.8
1934	22.5

Due to the fact that this station acts as stand-by, it may be called upon for rapid increases in load in emergency. These changes are made at the rate of 10,000 kw per minute. Due to the fact that boilers are pulverized coal-fired they respond rapidly to load changes. Adjustable limits are put on turbine governors to prevent units from picking up enough load in the case of emergency to draw a slug of water over to the turbine. Once the units have picked up to the limit permitted, the operator moves the limit and picks up load on the units at a prescribed rate.

The results of load pickup tests are of great interest. To determine the rate at which load could be picked up, load on one unit was increased from 5,000 to 85,000 kw as rapidly as possible, the load being decreased on the other unit by the same amount at the same time. This transfer of load was made in 33 seconds without evidence of strain on either machine.

A similar test was made on the boilers, the steaming rate of one of the boilers being increased from 110,000 pounds per hour to 320,000 pounds per hour in 2.7 minutes. Under this condition the control shut off the feed water entirely and the boiler water level rose $7^1/_2$ inches. This demonstrated that at this station the allowable rate of load pickup was dependent on the increase in drum water level and not on the increase in combustion rate available. Figures 5 and 6 on page 637 are very interesting to examine.

The heat balance of the machines appears too complicated to install when sacrifices of single cylinder machines were made for saving in space and fixed cost. It would be hard to justify 4-stage feed heating with such a low capacity factor.

A minimum load of 5,000 kw is interesting in connection with an 80,000-kw unit and the features of the design which make it possible would be of interest.

R. A. Hentz (Phila. Elec. Co., Pa.): It was interesting to note from figure 10 that the designers of the switchhouse had adopted the group-phase indoor design. Of the 4 general types of switching station design, namely (a) group-phase indoor, (b) isolated-phase indoor, (c) outdoor, and (d) metalclad, the Philadelphia Electric has had experience at 13.2 kv with all but the latter. In the earlier generating stations the group-phase indoor was used. In the Richmond station, completed about 1925, isolated-phase was employed. However, cost considerations and a bad shutdown experienced with isolated-phase there decided the Philadelphia Electric Company in favor of the outdoor design for the next 13.2 kv switching installation to be built, which was the Westmoreland transmission substation completed in 1928. Unfortunately, space did not permit the use of the outdoor design at the Conowingo hydroelectric generating station, also completed in 1928. Group-phase indoor was used there.

The Westmoreland substation is designed along the same lines as used in the Philadelphia Electric Company's 66 and 220 kv substation; that is, completely outdoor with each of the 2 busses on opposite sides of the station. We have had one case of trouble due to opening a bus disconnecting switch under load. The resulting flash caused such inconsequential damage that the bus was ready to be put back into service in a few minutes, whereas similar faults in indoor compartment design have caused damage that required several hours to clean up. In our opinion the outdoor

design is more reliable and cheaper than indoor, though it does take up more ground area than the indoor type, particularly the isolated-phase construction.

It would be interesting to hear from the author whether such outdoor construction was considered for Huntley No. 2 and the reason for selecting the switchhouse design adopted instead of any of the other types referred to above.

F. W. Gay (United Engrs. and Constructors, Inc., Newark, N. J.): Huntley Station No. 2 has relatively large transformer banks connecting the 22 kv and 110 kv networks. If the station could have been designed with a generator and transformer adjacent, then each generator could have been connected through gang-operated disconnecting switches and relatively short leads to a tertiary transformer winding.

Incremental transformer capacity between the tertiary and 22 kv busses would have been needed and obviously the associated transformer bank would have to be temporarily disconnected each time its generator was connected or disconnected. The autotransformers and their associated 22 kv oil circuit breakers would not have been needed, but, on the other hand, additional 110 kv equipment would probably have been required.

S. M. Dean (The Detroit Edison Co., Mich.): To me the title of this paper seems narrow. What H. M. Cushing has really done is to outline the situation which existed on the Niagara Hudson system in 1929 and to show how Huntley Station No. 2 was designed to fit into that situation. His tabulation of the specific design requirements is excellent.

How the station was designed for quick response to load changes so that it might stand as running reserve for the protection of the western end of the Niagara Hudson system, and more particularly for the city of Buffalo, is most interestingly told. The devices employed to accomplish this quick response, and the curves of performance form a valuable part of the paper.

Also, the necessity for the plant operating at the low and widely varying annual capacity factors inherent in such a combined hydro and steam system and how refinements not consistent with such operation were kept out is nicely brought out. Again, somewhat detailed operating results are tabulated for a range of capacity factors.

While not new in principle, the split bus scheme of electrical connections employed is interesting. The high reactance between sections as used in combination with feeder reactors provides sharply localized voltage disturbances under fault conditions. That is not only desirable from the point of view of the electrical system but also lends itself to the requirements of the power plant auxiliary system in that the voltage disturbances on the main electrical system are not generally distributed over the auxiliaries. It is interesting to see how they accomplished this result.

I note that duplicate busses and switchgear are employed. It would be interesting to know what, in the operating experience of Mr. Cushing's company, caused them to go to this rather large expense in a plant otherwise so carefully designed to keep down costs.

In brief, Mr. Cushing's paper is unusual because it tells a rather complete economic story. It gives the background against which to judge the plant, sets forth the design requirements, shows to what degree these results were accomplished, and gives an idea of what it cost to do so. Such papers are not only useful to designers, but also to system engineers, and by no means their least value is to the younger engineers. It is an excellent paper and I hope we may have more of this character.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): H. M. Cushing's paper is an excellent description of a job well done and covers the subject so thoroughly that there is not much left on which to comment.

It is interesting to note that the engineers' study showed it was more economical to design the generators for 13,800 volts and step-up to 22,000 volts by means of an autotransformer rather than wind the generators for 22,000 volts direct.

In most cases this will be true to a varying degree depending on whether graded insulation can be used in the generator winding or not. Until very large generator capacities are reached, 200,000 kva or more, there is no advantage in raising the voltage above 13,800 if only the generator is considered, but the difficulty of handling heavy currents and the danger of heating in wall beams if the generator and autotransformer cannot be kept in close proximity, will frequently justify the greater cost of high voltage generators even in units of the size here in question (100,000 kva). The split bus scheme used is certainly of advantage and is readily obtainable with an autotransformer. In some cases it may be difficult to obtain the necessary double-winding in a high voltage generator to adapt it to the split bus scheme.

The idea of purchasing the circuit breakers in a factory assembled structure is consistent with modern trends. These structures containing 0–33 and 0–44 breakers are of a simplified design which does not permit of speedy removal of the breaker, but this is justified in view of the bus and breaker arrangement selected and, as Mr. Cushing points out, presents a considerable saving in cost.

A statement is made that on occasion the frequency is regulated from Hell Gate station. It would be interesting to know what measures are taken to control load divisions for this setup.

A. R. Smith (nonmember; General Electric Co., Schenectady, N. Y.): H. M. Cushing's description of the Huntley Station No. 2 is a most complete one and illustrates how carefully their problems were studied in designing the plant and selecting equipment, with the result that they have a most appropriate one for a greatly fluctuating electrical load, which is always a difficult thing to take care of.

It is not clear as to what constitutes a generating unit as covered by table I which gives "hours idle, but unavailable." Perhaps, this includes more than the turbine generator. The record, however, is not a very good one. One of the reasons for a considerable out of service time was to make the turbines capable of quick starting to take care of the variable demand. Both units were found to be smooth at all loads, but No. 2 unit was sensitive to sudden changes in load and consequently much less stable than No. 1, although they were identical machines. In 1932, the rotor was returned to the factory for a thorough examination and some modifications, but the reinstallation of it showed no improvement.

In 1933 the rotor was again returned for a new shaft as a conclusion had been reached to the effect that there must have been some fault in the shaft which gave it such peculiar characteristics. This analysis was apparently correct, as the machine has acted normally ever since.

These 2 occasions on No. 2 unit would account for more than half of the total lost time listed in the tabulation for the 2 machines and were attributable to an unstable forging.

H. L. Wallau (Cleveland Elec. Illum. Co., Ohio): Nine requirements are set forth as having guided the engineering decisions made in the design of this plant. Let us consider them in order:

Rapid response to sudden changes in load. That the turbines selected meet this requirement to an extraordinary degree is shown by the results of the bold test made by the designers after the plant was completed, in which load was transferred from one unit to the other at a rate of 145,000 kw per minute.

The designers are also to be commended upon having devised a method of putting a unit of this size on the line in 25 minutes, if necessary. This time compares most favorably with the 20 minutes required for the Great Western Power Company's 35,000 kw units.

However, when one turns to the boiler plant one finds that due to the selection of a type of boiler with a single steam drum, the change of water level, even with normal steam pressure, limits the rate of pickup under operating conditions to 10,000 kw per boiler, 20,000 to 30,000 kw total, since ordinarily only 2 or 3 boilers would be on the line simultaneously. Had a multi-drum boiler been selected a considerably higher maximum pickup rate would have been feasible. An improvement in rate, if desired, could be obtained by the installation of auxiliary steam drums in the boilers.

This initial requirement, it is stated, called for a simple steam cycle. Four-stage bleeding, with 4 bleeder heaters, 2 evaporators, and an evaporator condenser, does not seem in entire agreement with the premise.

Maximum reliability. This requirement does not seem to have been met, apparently not because of faulty plant design, but because of trouble in major equipment, since the turbogenerator availability factor as determined from table I is 78.6 per cent. It is probable that corrective measures are being applied to improve this ratio.

It must carry its full capacity continuously for months at a time. This requirement, coupled with operating experience at Huntley No. 1, seems to have dictated the installation of a fourth boiler. Experience figures

are quoted showing the availability factors for boilers to be lower than for turbines and from which the conclusion is drawn that for unit type plants availability lies within the probable limits of 80 to 87 per cent. While granting the premises, I cannot agree with the conclusion, because the percentages of nonavailability include "scheduled cleaning and overhaul" and all outages are assumed as noncoincident.

In the case of schedule maintenance the length of outage is often governed by the need or lack of need of the unit for service. A job requiring 160 crew-hours may be done in 4 weeks by a single crew working 40 hours a week, but if the equipment is really needed, 3 crews will be put on, working 24 hours a day, and the job will be completed in one week. The reported availability factors, while based on experience, are low because in many cases there was no need to speed up the repair job.

Also, it will generally be the practice to overhaul both the boiler and turbogenerator units and accessories during the same period, so that even with overlap the total time unavailable will be the duration of the combined jobs from start to completion of both, but not the sum of their individual durations.

From table I the total elapsed time for both generators is found to be 68,841 hours, or an average of 34,420 hours per unit. From table II we find that the boilers were on bank for a total of 61,475 hours, and active for 76,996, hence available for service 138,471 hours, or an average 34,618 hours per boiler, which indicates apparently a 100 per cent availability factor.

Since 3 boilers will carry the full plant capacity the installation of the fourth does not seem justified in the light of this experience.

Low installation cost per capacity. This has been achieved. The total and unit cost is available to any one who will dig it out. Nevertheless, had the fourth boiler been omitted the plant cost would have been lowered by almost 5 per cent. However, the heat cycle chosen and previously referred to is a complex one for a low cost plant. A plant of comparable magnitude, 3 50,000 kw units, designed with but 2 stages of bleeding, no evaporators, no air preheaters, and working at 375 pounds at the throttle, 50 pounds less than Huntley No. 2, operated during the 12 months of 1934 under slightly less favorable conditions than did Huntley No. 2 during the last seven months of 1933, with better thermal economy. The average load was 58.8 megawatts as against 64.5, the capacity use factor 1.2 per cent lower, the net turbine water rate 145 pounds lower, and the Btu per net kilowatt-hour output 13,576 as against 13,812 for the Huntley No. 2 station.

The 4 multi-drum boilers have a maximum steaming rate equivalent to 3 of the Huntley No. 2 boilers. The costs per kilowatt of these 2 boiler plants are practically identical, the actual investment being somewhat less than that of the Buffalo plant. In this plant the saving of the heat loss from the generator air cooler was deemed worth while although the heat loss from the oil cooler is not recovered.

Low operating and maintenance costs. Figure 15 shows total relative costs for various monthly outputs and, making allowances for the fixed charges on the plant investment, this requirement has been reasonably met.

It must supply an expected 100,000 kw load in Buffalo. The criterion that 100,000 kw of load in Buffalo must be carried on this plant could be met with a 3 boiler plant of the type selected, 2 of which could furnish 1,056,000 pounds of steam, so here again the installation of a fourth boiler seems superfluous.

Relatively large units should be used. A choice of units of an individual capacity of about 15 per cent of the system peak load is in line with conservative engineering.

Initial ties of 210,000 kw for local load and 120,000 kw for interconnection. The initial installation of local subtransmission circuits of over 200 per cent of maximum load when these circuits are not only underground but in many cases feeding low voltage networks seems excessive. However, it affected the plant design only in the initial space requirements necessary for housing the 22 kv breakers and in the cost of both. The investment for the 22 kv and 110 kv feeders was kept low and the switch house layout made simple.

Building design must not restrict choice of future equipment. This requirement seems to have been met by the building design provisions which will permit of 200,000 kva tandem units being installed if found desirable so to do.

In conclusion, the most serious defect is the limited capacity of the steam drums of the boilers installed, restricting quick pickup of load, which defect can be remedied by the installation of auxiliary drums. If such a program were undertaken, the presence of the fourth boiler would greatly facilitate the change since 3 boilers would be available for normal operation, 2 of which could handle the maximum load of the Buffalo area.

Rehabilitation of the Conners Creek Plant

Discussion of a paper by R. E. Greene, published in the June 1935 issue, pages 610–17, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935.

C. M. Gilt (Brooklyn Edison Co., Brooklyn, N. Y.): The problem presented by the existence of more or less obsolete generating plants and the need for increased capacity is one that will become more pressing for many power companies as load increases during the next few years. The choice must be made between building a new plant and retaining the old for reserve and peak duty, building a new plant and scrapping the old one, or rebuilding the old plant. There is no general solution to the problem but each case must be settled on its merits.

Quite frequently an old plant can advantageously be kept for stand-by and peak load service, thereby postponing the investment necessary for new capacity. Its cost per kilowatt-hour generated may be extremely high and yet its annual cost may be materially less than the carrying charges on the equivalent new capacity. When the time comes that the old plant must be scrapped, it would usually be cheaper if the old plant were nonexistent and one could start fresh with no encumberances. Sometimes the old plant can be rehabilitated for a time at a low cost by changes in parts of the plant, or by superimposing high pressure units, that improve economies or increase the capacity or both.

Rebuilding an old plant usually requires retiring part or all of the old capacity with the result that while the net addition to capital for the modernized plant may not be great, the new money required for the additional capacity may be quite high.

The figures given in R. E. Greene's paper for new money plus the value of equipment from other locations amount to $20,826,610 for an increase in capacity of 150,000 kw, or $139 per kw. However, Mr. Greene states that the old plant would have to be retired shortly under any program, and would be of little value in the meantime. Recognizing the necessity for this retirement, 150,000 kw increased capacity has been obtained for $13,884,755 net addition to capital, or at $92.50 per kw, and a modernized and more efficient plant of 330,000 kw capacity has been obtained with a total book value of $30,367,200 or $92 per kw, a cost per kilowatt about the same as that of the old plant.

Comparing these figures with costs of totally new plants, it would appear that the choice of obtaining the added capacity by rebuilding the old plant rather than building a new one to supplement it was largely determined by the judgment that the old plant should be retired under any condition, plus the fact that by gradually rebuilding the old plant, the large initial expenditures associated with starting a new station would be avoided.

It would seem evident that a load district method of operation in which each generating station largely supplies its own district load, furnishes an incentive toward more rapid rebuilding or scrapping old plants than one in which new and economical plants feed the system as a whole and old plants can be relegated to short hour use as reserve or peak duty for the system as a whole.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Rehabilitation is always interesting because the problems it presents are much more difficult than in building a new plant. R. E. Greene's company selected a method of rehabilitation which worked out particularly well in their case because they were able apparently to utilize a great deal of the existing parts in the rebuilt assembly. I wonder if, under the circumstances, the statement is justified that high pressure units superimposed on the old machines would have resulted in higher maintenance and lower reliability, inherent in old equipment. In any scheme of rehabilitation if it is to be economical, considerable old equipment must be retained and the weak member in reliability may not be the main units. With superimposed turbines the life of the existing equipment enters the problem to no greater degree than it would if the station were left at its original pressure. When the decision has been made to replace the old boilers by higher pressure units, the question of the old turbinegenerators should be treated as a separate problem. The turbines need

not be rebladed or the generators rewound any sooner because of the superimposition of high pressure equipment, and these operations are about all that is necessary to maintain the life of the units almost indefinitely.

D. F. Pennell (nonmember; Brooklyn Edison Co., Brooklyn, N. Y.): The most interesting point for consideration in the paper on Connors Creek plant is the amount of old equipment it was possible to use in the rehabilitation. The following pieces of equipment were used of the original plant:

a. Building and foundations (with addition to turbine room).

b. Stacks.

c. Coal handling equipment.

d. Condensing equipment including condensers originally installed with 20,000 kw units but adapted to 30,000 kw units by use of improved tube layouts and extraction heaters, also condenser auxiliaries

e. Circulating water tunnels.

In addition to this, 2 30,000 kw generators were used that had been salvaged from Connors Creek and Delray No. 2.

Included in the construction of the new machines are the exhaust casings of 3 of the 20,000 kw units and the pillow blocks of the old 30,000 kw units. Nearly all the piping, including service piping, had to be replaced to meet the new requirements.

In spite of the amount of this equipment it was possible to salvage, the installed cost per kilowatt-hour does not reflect any great saving.

Original capacity	180,000 kw
Expected capacity	330,000 kw
Increase	150,000 kw

Net increase in book value = $13,880,000
Cost per kw increased capacity = $92.50

It appears that with the same investment 2 large units might well have been installed giving the same increase in capacity and thermal economy and that these units could have been added when, as, and if needed without interrupting normal operation of the old plant.

One statement made by R. E. Greene is interesting to note. He says, "At the start it was recognized that certain predilections existed in the minds of the operating staff, and it was agreed that these should be tested and followed out only when found to be sound." As a matter of practical design, it might be better to reverse this and follow these so-called predilections unless they prove on analysis to be unsound.

The author also states "the electrical system of the Detroit Edison Company is divided into load areas interconnected by ties for mutual help in emergencies." This electrical layout of the Detroit system appears to give the plant designer a somewhat different angle of attack than we would have in Brooklyn. It complicates the problem by making it necessary to predict not only changes in system load but to predict where these changes will occur. In New York, however, we build for the system load and due to adequate interconnections have the economy resulting from interchange of power. By this method we are able to supply the system base load with the most modern generating equipment, taking advantage of the economy of first cost and operation that goes with large generating units and using older stations for stand-by and peak load capacity.

One reason given for revamping the old plant is that in addition to high maintenance costs the "reliability would be not of high degree." This is a minor point but I feel that our experience is that old equipment properly maintained gives a satisfactory degree of reliability. Oftentimes it is more reliable than new equipment that tends toward the experimental.

Complex Hyperbolic Function Charts

Discussion of a paper by L. F. Woodruff published in the May 1935 issue, pages 550–4.

A. E. Kennelly (Harvard University, Cambridge, Mass.): The charts offered in the paper will be serviceable to transmission engineers and to all those who are interested in alternating current lines having at operating frequency an angle not exceeding 0.4 in size.

The charts possess an unusual feature from a mathematical standpoint. In order to find certain desired trigonometrical functions of the line angle $\theta \left(\text{namely } \cosh\theta, \frac{\sinh\theta}{\theta}, \text{ and/or } \frac{\tanh\theta/2}{\theta/2} \right)$ one enters the curvilinear system of each chart with the size and slope of θ^2; i. e., $|ZY|$ and $\overline{ZY}$, then reading off the size and slope of the function on the semirectilinear ruled background. This unusual procedure reasonably claims a lessening of time and effort in the process.

The Sparkless Sphere Gap Voltmeter

Discussion and authors' closure of a paper by R. W. Sorensen, J. E. Hobson, and Simon Ramo, published in the June 1935 issue, pages 651–6, and presented for oral discussion at the selected subjects session of the summer convention, Ithaca, N. Y., June 27, 1935.

A. O. Austin (consulting engr., Barberton, Ohio): The authors have carried out a very effective method of checking root mean square values with means at the disposal of practically any high voltage laboratory. Anyone making high voltage measurements is continually running up against conditions upon which it is desired to make a check, and since the method involves no elaborate equipment it can be readily carried out. Where the wave form is good the method may be used for checking crest values. It would seem that the method is primarily applicable for calibration purposes. The capacitance calculations of the sphere gap can also be used very effectively for determining crest voltages which I believe have a wider application than the determination of root mean square values. With the close control of frequency the determination of voltage with an ammeter in series with a capacitor of known capacitance is very simple.

While the capacitance tap on bushings or condensers is one of the most useful methods in determining high voltages in the laboratory, it is necessary that the capacitance of the condenser supplying current to the insulating instrument does not change with voltage due to corona from the leads or field et up by external objects. It is hoped that the calculations in connection with the capacitance of spheres will be carried further and limits established so that the sphere gap may be used as a capacitor for direct checks upon the crest voltage. This is based upon the fact that $I = EC\omega$, hence $E = \frac{I}{C\omega}$. This method has proved to be very useful and makes it unnecessary to subject equipment under test to an oscillation following a discharge of a parallel gap.

The accuracy of this method of determining crest values depends primarily upon the accuracy of the capacitor. R. W. Sorensen's calculations would indicate that the sphere gap may be used to supply the needed capacitance. Irregularities which affect the discharge of a sphere gap also have an effect upon its capacitance, and will have to be determined within fairly close limits. It is to be hoped that R. W. Sorensen will continue his work and determine the necessary limitations. With a capacitor of known capacitance it is possible to use a ballistic method to determine transient voltages to advantage in many cases. With R. W. Sorensen's method it would be possible to show some of the irregularities of the sphere gap and to obtain a further check upon calibration curves.

For normal frequency tests it has been evident that the needle gap gave far more consistent results based upon transformer ratio than sphere gaps for normal frequency determinations up to 350 or 400 kv. The capacitance measurements for the sphere gap calls attention to the errors which may occur where an attempt is mane to measure crest transient voltages with a resistance in series with a gap.

It is to be hoped that the work outlined in the paper will be continued, and that the advantages and limitations of the various methods will be given due consideration as a single method will not give the best results for all conditions.

J. R. Meador (General Elec. Co., Pittsfield, Mass.): The authors have presented a very interesting paper on voltage measurement. It is especially timely since the A.I.E.E. standard sphere gap calibration curves are now being revised. It is important to have data taken by as many different methods as possible. Using the method of voltage measurement described by the authors, a check can be made on the 60 cycle calibration curves for sphere gaps, which have been recently recommended ("Calibration of the Sphere Gap," J. R. Meador, ELEC. ENGG. (A.I.E.E. TRANS.), v. 53, June 1934, p. 942–8; "Impulse Calibration of Sphere Gaps," P. L. Bellaschi and P. H. McAuley, *Elec. Jl.*, v. 31, June 1934, p. 228–32).

Although the experimental curve in figure 4 does not agree closely at large spacings

with the recommended curves mentioned above, it is about what should be expected if the position and mounting of the 100 centimeter spheres are considered. In figure 1, I have shown curves illustrating the general effect of gap position. These curves show the 60 cycle spark-over of a 50 centimeter sphere gap, (1) vertically mounted with the lower sphere grounded, (2) horizontally mounted with one sphere grounded, and (3) vertically mounted with the upper sphere grounded. In all tests the spheres were approximately 4 diameters above ground. For comparison the calculated calibration curve for one sphere grounded is included.

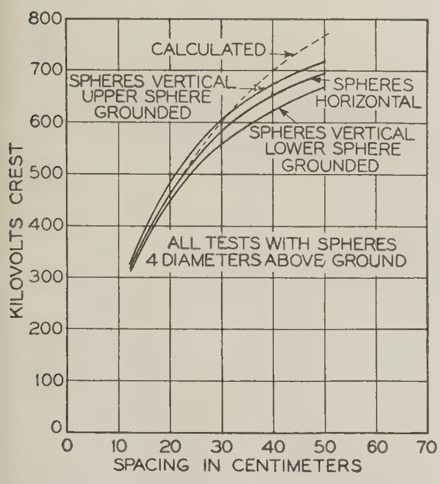


Fig. 1. 60-cycle spark-over of 50 centimeter sphere gap having one sphere grounded

The curve for horizontally mounted spheres agrees fairly closely with the calculated curve up to 40 per cent of diameter spacing. Above this spacing the test curve falls below the calculated curve by 3 per cent at 60 per cent of diameter spacing and by 7 per cent at 80 per cent of diameter spacing. The authors' figure 4 appears to have very similar characteristics. For spacings above ground of more than 4 diameters the difference between the calculated and tested curves probably should be slightly less. The curve in figure 1 for vertically mounted spheres having the upper sphere grounded shows a condition in which the effect of ground is considerably reduced.

I would suggest that the authors use their 100 centimeter spheres as the measuring device for calibration of other sizes of spheres having a more conventional mounting. Where voltages of a large range of magnitude are to be measured, several sizes of sphere gaps are necessary and it is usually more convenient to have them mounted in portable frames.

In connection with the use of this method of voltage measurement for apparatus testing, I would like to ask the authors whether the voltage can be raised to a predetermined value without adjustment of the weights. That is, is it necessary to raise the voltage and then measure it by adjusting the weights, or can all adjustments for a certain voltage be made before voltage is applied?

The principal advantages and disadvantages of the sparkless sphere gap voltmeter for general high voltage measurements, that were not mentioned by the authors, appear to be as follows:

Advantages

1. For high potential tests on completed apparatus the spark-over of a gap at the apparatus terminals is eliminated.

Disadvantages

1. The device does not appear to be portable.
2. The wave shape of the applied voltage must be known since certain types of loads may distort the 60 cycle voltage wave appreciably.

J. B. Whitehead (Johns Hopkins Univ. Baltimore, Md.): The use of the electrostatic attraction principle for the measurement of voltage is old. The Kelvin absolute electrometer was one of the earliest methods proposed for the measurement of voltage. As an absolute instrument it has the great advantage that its calibration may be computed from its dimensions. In recent years various forms of the electrostatic instrument have been proposed for the measurement of very high values of voltage. Most of these like the Kelvin instrument are equipped with guard rings and when the electric field at the surface of the moving element is uniform, the calibration may be computed.

Professor Sorensen's proposal to measure voltage by the force of attraction between the 2 spheres of a sphere gap greatly extends the area of the attractive surfaces, thereby increasing the force of attraction and so extending the range of the instrument. However, it is not possible to compute the calibration; this must be separately determined owing to possible influence from surrounding objects, and in any event to the influence of the supports, on the distribution of the total field. That these effects need not be great in the lower range of any particular gap is shown by the agreement between his observations and those determined by the spark-over.

The curve shown between attractive force and voltage for any particular gap setting is interesting, in that it contains a maximum of force with decreasing value above a definite voltage. I venture to suggest the possible influence of space charges in explaining this apparent discrepancy. At the higher voltages local, and generally invisible point ionization may be expected from minute irregularities on the surface. The velocities of the resulting ions may be so great as to cause appreciable gaseous space charges near the sphere surfaces in each half cycle, which would have as their result higher values of gradient at the surfaces than that corresponding to the undisturbed field and so a counter polarizing e.m.f. over the total gap. Unequal potential gradients under alternating stress in solids has recently been reported by Bôning.

Eric A. Walker (Tufts College, Medford, Mass.): The authors have made some refinements on a well known principle for measuring voltage. A high voltage voltmeter, electrostatic in character but having a different method for measuring the torque, was constructed some 10 years ago by Prof. C. L. Dawes at the Harvard Graduate School of Engineering. The general scheme was as follows: 2 25 centimeter spheres were used, both being insulated from ground, having between them a variable air gap. Between these spheres was supported on a galvanometer suspension a mechanism consisting of 2 3 centimeter spheres fixed to the ends of a metal rod about 10 centimeters in length. The center of the rod was soldered to the suspension so that the rod and spheres hung in a horizontal plane. The suspension was so oriented that normally the smaller spheres hung perpendicular to the center line of the large ones. When the potential was applied to the larger spheres the suspended mechanism would rotate and tend to line up with the electric field due to the attraction of the induced charges. A small mirror was mounted on the suspension and a beam of light so focused that its reflection from the mirror fell on a calibrated scale. This scale consisted of a strip of transparent celluloid bent so as to include about a 120 degree arc of a circle having a radius of 3 meters. As there was some tendency to oscillate in the suspended mechanism at low frequencies, 10 to 25 cycles per second, a dash pot and vane was fastened to the lower end to damp out any vibration. The high voltage elements were all electrostatically shielded.

By the mechanism the root mean square value of any high voltage wave could be read quite accurately. Unfortunately this type of meter does not have a linear calibration curve. No mathematical analysis of its performance was attempted but the meter was calibrated for various gap settings by means of a high voltage transformer, having a tertiary or voltage coil, which was fed from a sine wave generator. The meter was used for measuring continuous battery voltages up to 50 kv.

This meter has little value in breakdown tests on insulation unless the wave form of the testing voltage is known. Moreover, if the wave form is known, and does not change with voltage, the peak voltage may readily be calculated from the value indicated by the tertiary of the transformer.

K. B. McEachron (General Elec. Co., Pittsfield, Mass.): It seems to me that any method from which the geometry of the active parts may be calculated without the use of empirical relations should be of more fundamental nature than the sphere gap now in use. Therefore, I am of the opinion that other laboratories should follow the invitation given in the paper to check and extend this method of voltage measurement. Such work is to be undertaken in the high voltage engineering laboratory at Pittsfield, Mass.

However useful this method may be as a standard, I do not believe that it will supplant the sphere spark gap, particularly in the large sizes, on account of the greater space which would undoubtedly be required and its inability to measure transients.

No doubt ballistic measurements could be made which would give some measure of transients, but since the crest of the wave is desired and the wave shape may be unknown the ballistic method does not appear to be promising.

Conclusion 6 of the paper may be difficult to carry out when testing apparatus which flashes over as a part of the test since oscillations are frequently set up which will cause a flashover of the sphere gap even when the spacing is relatively large compared to the normal frequency sparkover potential.

For tests involving flashover it would be more desirable to have the sphere gap indicate crest potential rather than effective, since frequently the wave form may be seriously affected by the test piece.

The freedom of corrections for air density now applied to the sphere spark gap constitutes a definite advantage for the method described in the paper.

More data should be obtained with reference to the effect of surroundings and method of mounting the spheres whether vertical or horizontal. Additional data will also be needed on other sizes of spheres. All of this is work which should be undertaken by other laboratories to supplement and extend the work of the authors.

W. A. Hillebrand (Univ. of Calif., Berkeley): In spite of its limitations, the sphere gap as a spark gap voltmeter will continue to be used for 2 reasons, convenience and the fact that it measures crest values. However, the authors' demonstration that a pair of spheres may, with comparatively little auxiliary apparatus, be used as an electrometer with a high degree of accuracy, is a welcome contribution to the technique of high voltage measurement because it affords an independent calibration of the spark gap voltmeter or of a testing transformer itself.

Since the force between the spheres varies as the square of applied voltage, a one per cent voltage fluctuation results in a 2 per cent variation in attractive force. The resulting displacement tends to alter the force in the same direction, so that the method is inherently unstable unless the applied voltage is quite steady. Although the authors indicate that such fluctuations are rendered unimportant by the inertia of the spheres themselves, I would like to be reassured on this point. Can the authors indicate the permissible range of voltage fluctuation within which it is possible to use the sphere gap satisfactorily as an electrometer?

Also, have the authors made any calculation of the attractive force between 25 centimeter spheres up to 250 kv root mean square?

R. W. Sorensen: The many encouraging comments regarding the value of re-establishing a voltmeter which can utilize the mechanical forces between charged bodies as a measure of voltage, and the willingness of others to include work with the nonarcng sphere gap in their research programs are indeed pleasing rewards for the work done in presenting this paper. Its authors have had a real delight in watching the first simple experiment in their program (which consisted simply of suspending one sphere by a long rope near a second sphere rigidly mounted, applying potential to these spheres and noting the motion of the free one) grow into a device which gives very satisfactory readings of what may turn out to be true voltage values, although as yet we do not feel that sufficient work has been done to warrant calling our figure 4 a calibration curve. The reasons why this should not be done are insufficient cross checking to date with present accepted voltage standards for sphere gap sparking distances; the lack of other convenient standards with which to compare these results, and the fact that our laboratory conditions were such as to cause us to get our spark-over values of voltage with the spheres in a horizontal position rather than mounted vertically according to standard practice. If the relation between readings made with spheres horizontal and readings made with spheres vertical is the same for 100 centimeter spheres as that shown for the 50 centimeter spheres by Mr. Meador in his discussion, we will indeed find to the gratification of everyone our tests in close agreement with the proposed new A.I.E.E. sphere-gap spark-over values.

In response to J. R. Meador's suggestion that we use our 100 centimeter sphere nonsparking arrangement to check other sizes of spheres with conventional mountings, may I say that we are proceeding to do that very thing, and have already purchased for such tests a pair of 50 centimeter standard spheres.

Answering Mr. Meador's question, I would like to state that we can very conveniently place on the weight pan the proper weight for any given voltage and then raise the voltage to the value required to give a pull that will balance the weight.

The portability of the spark-over sphere gaps is a real factor in its favor and is a feature not too easily embodied in the design of nonarcing gaps, but I am not ready to say means will not be found whereby nonarcing gaps may be made portable. Also, it seems to me most of the 100 centimeter sphere gaps I have seen are quite securely mounted on brackets attached to building walls and hence are not very portable. Perhaps when we get acquainted with small force measuring gaps we will find ways for making them almost as portable as are the arcing sphere gaps of like size, hence it may be that even though our enthusiasm for the nonarcing gap has been based on its possible use as a primary standard supplementing the arcing sphere rather than supplanting it as questioned by K. B. McEachron, the authors of the paper have a sincere expectation of a rather wide run of nonarcing sphere gaps in high voltage testing.

Ballistic measurements for transients are a consummation greatly desired with this type of apparatus, and have been considered by the authors. In fact, a rather active program of investigation along those lines is now in progress. In this work there are difficulties set up by low mass desideratum for moving parts and features of construction and reading methods, but we still have hopes of finding solutions for these problems. For transients, particularly for very erratic wave forms I can quite agree with Mr. McEachron that crest potentials rather than effective voltage values are desirable, but for steady state or power frequency voltage testing it is highly probable that as our knowledge of the relations between voltage and insulation strength develops we will be more interested in effective rather than peak voltage values.

We have already set up models of rooms and sphere gaps for use in testing the effect of surroundings upon the forces between charged spheres and will have data from tests in due time. At the present moment I can report that we have found by a trial test with a $^1/_8$ scale model of our high voltage laboratory in which we use 12.5 centimeter spheres that voltage variations which cannot be noted on an ordinary a-c portable voltmeter cause more variation in the force between the 2 12.5 centimeter spheres than is caused by metal plates set up to represent the laboratory walls and ceiling. Arrangements are now being made to excite the transformers with a more constant voltage supply. We have used in our laboratory the method of measurement described by E. A. Walker and do not consider it as satisfactory for our purpose as the method we have described.

Dr. J. B. Whitehead's remark in speaking of guard rings reminds me of the great "bugaboo" we encountered in our plans for using some form of electrostatic meter. We considered electrodes of many forms and one by one abandoned them in favor of spheres with no attempt to use guard rings and we have realized our hope that surrounding objects would not produce enough disturbance to cause trouble. Our success with the spheres is due to my method of mounting which allows a free swing of the moveable sphere in one direction only and permits large clearance all about both spheres.

Our experience indicates that the surrounding objects influence force readings less than spark-over values and hence are less objectionable for our use of spheres than for the sphere gap voltmeter using spark-over distance as a measure of voltage. Also, I would disagree with Doctor Whitehead's statement concerning accuracy of calibration computations.

We feel quite certain that laboratory tests are going to show that the effect of surrounding objects, walls, etc., and even the effect of supporting shanks for the spheres, can be accurately calculated and accounted for in calculating the relation between force readings and voltage, with nonarcing sphere gaps.

The curve of figure 9 may teach us several lessons, one of which is why the spark gap voltmeter gets erratic at the larger spacings, but I doubt if we are at present prepared to say why the field strength and its influence on the force between spheres takes just the form shown by the curve.

We have made no checks to determine the permissible range of voltage fluctuations possible and cannot therefore exactly answer W. A. Hillebrand's first question, but in our work we have considered our source of voltage free from fluctuations to the extent required for good work. After a little experience with the nonarcing gap, one can by that means read voltages quite quickly, also the variations in voltage are gradual rather than sudden and are such that, as I have mentioned, they are quite unnoticeable on an ordinary portable voltmeter connected to the testing transformer voltmeter coil. I do not have with me a calculation for the forces between 25 centimeter spheres at different voltages, but such calculations may be quite readily made, as figure 8 and table III are applicable to any size spheres, simply by multiplying the sphere gap setting by the factor $R/50$ where R is the sphere radius in centimeters.

In conclusion may I point out that the deviations mentioned in the first paragraph of the résumé in our paper are caused by the erratic behavior of the spark gap voltmeter and not the sparkless gap voltmeter. The curve of figure 9 is the envelope of the ends of the curves of figure 10, and figure 4 is not to be considered as a calibration curve.

News

Of Institute and Related Activities

Great Lakes District Meeting and Student Branch Convention

THE meeting of the Great Lakes District of the A.I.E.E. will be held at Purdue University, West Lafayette, Ind., on Thursday and Friday, October 24 and 25, 1935. The Friday morning session of this convention will be devoted to the best papers selected from the various Student Branches of this District. All meetings, with the exception of the dinner meeting, will be held in the new electrical engineering building on the North Campus (directly on route 52 and 152 between Chicago and Indianapolis). Conference and club facilities including meals are available in the Purdue Memorial Union Building, 2 blocks from the meeting place. A varied technical program, a dinner, dance, inspection trips to the factory of the Duncan Electric Manufacturing Company in Lafayette and the various buildings and laboratories of the university have been arranged during the 2 day session to be followed by the university home-coming program and football game with Carnegie Institute of Technology on Saturday.

Technical Program

As may be observed from the accompanying tentative technical program, a wide variety of papers has been scheduled for presentation and discussion, most of which have had the approval of the national technical program committee and are being published in Electrical Engineering.

During the first session are included motor and meter design, motor starting methods and distribution problems. Particularly will the recently developed single phase and polyphase meters warrant an interesting discussion.

The second session is devoted to the very timely discussion of vacuum and luminous tube circuit theory and applications. "The Relaxation Inverter," recently described in Electrical Engineering, will be presented for further attention with new developments added by the author, Dr. H. J. Reich of the University of Illinois. Dr. C. S. Roys of the graduate staff of Purdue University, who is coauthor with Dr. Reich of a forthcoming textbook on electronics, and Dr. C. B. Aiken, formerly of the Bell Telephone Laboratories, who has recently joined the staff of the school of electrical engineering of Purdue University, will lead the discussion of this and possibly other papers of this group. "Firing Time of an Igniter Type of Tube" and the analysis of rectifier circuits by means of Fourier's series, both developments of the University of Michigan, have been approved as worthy contributions to the solution of these timely problems, while the University of Iowa presents a new electrostatic audio-frequency generator. Industry is also served by the discussions of applications of thermionic control to steel mill operations and of luminous lighting developments.

Previous District meetings have awakened the older generation of engineers to the worthy competition from Student members. The selected best papers, prepared by the Students of many of the universities of this District as listed upon the Friday morning's program, are no exception to this experience as to variety and quality of novel electrical engineering development. This is not a parallel session. All those registered will profit by the Student session.

Purdue University has specialized for many years in extra-high-potential research including the design, construction, and calibration of the surge generator, its accompanying cathode ray oscillographs and later the specialized development of the sealed-off cathode-ray oscilloscope with double image possibilities and its application to television. These will be discussed in papers and demonstrations to be presented by Prof. R. H. George and other local staff authors during the Friday afternoon session, while the University of Wisconsin contributes a study of potential distribution control over insulators, appropriately grouped under this specialized subject. The latest of a long series of lightning investigations on transmission lines, made by Lewis and Foust and published by the Institute, concludes this high potential program.

The oral discussion of these papers at the meeting in the foregoing manner is desirable but only discussion which is pertinent to the papers which have been published in advance will be acceptable for consideration for publication. Rules governing discussions of both unpublished papers and published papers are given in the following paragraphs on "Rules for Presenting and Discussing Papers."

Rules for Presenting and Discussing Papers

In general, the time allowed for the presentation of each paper should not ex-

Summarized Schedule of Events

Wednesday, October 23

7:00 p.m. — Dinner and conference for national, District, and Section officers as guests of Purdue University

Thursday, October 24

9:00 a.m. — Registration (Electrical engineering building)

9:30 a.m. — Opening Meeting. G. G. Post, vice president, A.I.E.E. Great Lakes District, *presiding*. (Main lecture hall, electrical engineering building)
Welcome: Dr. A. A. Potter, dean of schools of engineering, Purdue University
Technical Session: General Applications

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m. — Luncheon meeting of the District executive committee

1:00-2:00 p.m. — Inspection trip leaving Purdue Memorial Union Building for campus and laboratories

2:30 p.m. — Technical Session: Electronic Tube Theory and Practice

4:30 p.m. — Adjournment

7:00 p.m. — Dinner, ballroom, Purdue Memorial Union Building. Dr. E. C. Elliott, president, Purdue University, H. H. Henline, national secretary, A.I.E.E., and other A.I.E.E. officers, speaking.

Friday, October 25

9:00 a.m. — Student Technical Session

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m. — Luncheon meeting of committee on Student activities and Student Branch chairmen

1:00-2:00 p.m. — Inspection trip leaving Purdue Memorial Union Building for Duncan Electric Manufacturing Company factory in Lafayette

2:30 p.m. — Technical Session: High Potential Measurements

4:30 p.m. — Adjournment

5:00 p.m. — Television demonstration, lecture room 254, second floor, electrical engineering building, R. H. George and H. J. Heim, Purdue University

9:00 p.m. — Home-coming mixer dance, Ball Room, Purdue Memorial Union Building

Saturday, October 26

Morning—Informal university inspection and home-coming program

2:00 p.m. — Ross Ade Stadium, football game, Purdue University versus Carnegie Institute of Technology

Tentative Technical Program

In the following program, reference to the issue and page in Electrical Engineering is given for all papers which have been published therein. Others may be published in subsequent issues.

Thursday, October 24

After 9:30 a.m. Opening Meeting—Technical Session: General Applications. G. G. Post, vice president, A.I.E.E., and Dr. C. F. Harding, Purdue University, *presiding.* (Main lecture hall, electrical engineering building)

Address: Dare We Become Efficient? J. W. Esterline, president, Esterline-Angus Co., Indianapolis, Ind.

Split-Phase Starting of 3-Phase Motors, G. F. Tracy and W. E. Wyss, The University of Wisconsin — Scheduled for Oct. issue

A New Watthour Meter, Stanley Green, Duncan Electric Mfg. Co. — Scheduled for Oct. issue

Magnetic Fields in Machinery Windings, J. F. H. Douglas, Marquette University — Sept. issue, p. 959–66

Loads on Delta-Connected Transformers With Mid-Taps, N. G. Larson, Commonwealth Edison Co. — Sept. issue, p. 931–4

* A-C Electrolytic Capacitors, C. F. Lomont and F. S. Dunleavey, The Magnavox Co. — Scheduled for Oct. issue

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p. m.—Luncheon Meeting of the District Executive Committee

1:00-2:00 p. m.—Inspection trip leaving Purdue Memorial Union Building for campus and laboratories

2:30 p. m.—Technical Session: Electronic Tube Theory and Practice. C. A. Cora, chairman, Central Indiana Section, A.I.E.E., and Dr. C. B. Aiken, Purdue University, *presiding.* (Main lecture hall, electrical engineering building)

* Characteristics of Luminous Tube Circuits, C. M. Summers, General Electric Co.

An Electrostatic Audio Generator, E. B. Kurtz and M. J. Larsen, University of Iowa — Sept. issue, p. 950–5

Analysis of Rectifier Filter Circuits, W. B. Stout, University of Michigan — Sept. issue, p. 977–84

Address: Recent Electrical Developments in the Steel Industry, R. H. Wright, Westinghouse Electric and Mfg. Co.

Firing Time of an Igniter Type of Tube, W. G. Dow and W. H. Powers, University of Michigan — Sept. issue, p. 942 9

The Relaxation Inverter, H. J. Reich, University of Illinois — Dec. 1933 issue, p. 817–22

4:30 p. m.—Adjournment

7:00 p. m.—Dinner—Ball Room, Purdue Memorial Union Building, E. C. Elliott, president, Purdue University, H. H. Henline, national secretary, A.I.E.E., and other A.I.E.E. officers

Friday, October 25

9:00 a.m. — Student Technical Session. E. B. Kurtz, University of Iowa and A. N. Topping, Purdue University, *presiding.* (Main lecture hall, electrical engineering building)

Paralleling of Compound Generators Without Equalizer, John Miles and J. F. Palm, Michigan College of Mining and Technology

Single Phase Magnet Design, W. L. Ringland, Purdue University

The Magnetron on Ultra-High Frequencies, P. E. Haggerty, Marquette University

Structure and Operation of the Chicago Interconnected System, Charles McNamara, Lewis Institute

Developments in the Generation and Distribution of Power and Their Effect Upon the Consumer, David R. Bair, University of Iowa

Analysis of Lightning Arrester Volt-Time Curves, A. W. Rankin, Purdue University

A Different Method of Determining Reactive Volt-Amperes in a Three-Phase Three-Wire System, A. S. Webeck, University of Illinois

The Use of the Quartz Crystal in Radio Communication, B. E. Montgomery, Iowa State College

A New Vacuum Wattmeter Circuit, J. F. Chandler and J. C. Cunningham, Purdue University

Design of Cornices for Built-In Lighting, W. H. Budd, University of Michigan

Sweep-Frequency Limits of Gaseous Discharge Tubes, W. A. Dipp, University of Illinois

The Aluminum Electrolytic Condenser, W. A. Brastod, University of Minnesota

Color Organ, Brice Gilman, Milwaukee School of Engineering

Streamlining, Maurice Swanson, University of Wisconsin

Modulation in Radio-Telephony With a Note on the Physical Significance of Side Bands, Cyril Baranovsky, University of Minnesota

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m.—Luncheon Meeting of Committee on Student Activities and Student Branch Chairmen

1:00-2:00 p.m.—Inspection trip leaving Purdue Memorial Union Building for Duncan Electric Manufacturing Company Factory in Lafayette

2:30 p. m.—Technical Session: High Potential Measurements. A. G. Dewars, secretary, A.I.E.E. District 5; O. Kiltie, chairman, Ft. Wayne Section, A.I.E.E., and D. D. Ewing, Purdue University, *presiding.* (Main lecture hall, electrical engineering building)

* The Production of Impulse Voltages for Surge Testing, C. S. Sprague, Purdue University

Control of Potential Over Insulator Surfaces, Edward Bennett and G. L. Fredendall, University of Wisconsin — Scheduled for Oct. issue

* The Purdue Cathode-Ray Oscilloscope With an Electronic Switching Circuit for the Simultaneous Observation of 2 Waves (Demonstration), R. H. George, H. J. Heim, and C. S. Roys, Purdue University, and H. F. Mayer, General Electric Co.

The Effect of Ultraviolet on Breakdown Voltage, G. L. Nord, Western Railroad Supply Co. — Sept. issue, p. 955–8

Lightning Investigation on Transmission Lines—V, W. W. Lewis and C. M. Foust, General Electric Co. — Sept. issue, p. 934–42

5:00 p.m.—Television demonstration, lecture room No. 254, second floor, electrical engineering building, R. H. George and H. J. Heim, Purdue University

9:00 p.m.—Home-coming mixer dance, Ball Room, Purdue Memorial Union Building

Saturday, October 26

Morning—Informal university inspection and home-coming program

2:00 p.m.—Ross Ade Stadium, football game—Purdue University vs. Carnegie Tech.

* These papers may be presented but they have not been accepted for publication at the time of going to press.

ceed 10 minutes unless otherwise arranged with the chairman of the program committee, Dr. C. F. Harding, Purdue University, West Lafayette, Ind., or unless the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Each speaker unannounced by the presiding officer is to step to the front of the room and announce, so that all may hear, his name and professional affiliation.

Discussion of Unpublished Papers. Those wishing to discuss any of the unpublished papers should write to Dr. C. F. Harding (at the above address) for mimeographed copies. It is suggested that discussers be limited to 10 minutes each, and preference will be given to those who have sent copies in advance to Doctor Harding, chairman of the program committee. After these discussions have been given, the meeting will be opened for general discussion. The discussions of the unpublished papers will not be considered for publication.

Discussion of Published Papers. The same procedure governing the presentation of discussions of published papers should be followed as for the unpublished papers except that the written discussion to be submitted for consideration of publication should not be longer than the equivalent of 5 minutes' reading time. Discussion to be considered for publication should be based only upon the published papers and it must be submitted in triplicate (one of these copies to be the original, typed double spaced) to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before November 8, 1935. Discussion received after this date will not be accepted.

Convention Dinner

Tickets at $1.50 per plate should be secured as early as possible at the Registration desk for the dinner to be held in the ballroom of the Purdue Memorial Union Building on Thursday evening at 7:00 p.m. Music and other entertainment will be provided during the dinner and brief remarks by President E. C. Elliott of the university, and the A.I.E.E. national officers will be enjoyed. The women are particularly invited to attend this dinner. No provision for dancing has been made for this evening as the customary home-coming dances may be enjoyed by all in attendance on the following Friday and Saturday evenings.

Inspection Trips

Although all of the buildings and laboratories of the university will be in normal operation, and open to all, throughout the 2 days of the convention, a more formal personally conducted tour, starting at the Purdue Memorial Union Building, has been planned for Thursday from 1:00 to 2:00 p.m. On Friday, at the same hour, automobiles will leave the same meeting place for an inspection of the plant of the Duncan Electric Manufacturing Company and other points of interest in Lafayette.

Purdue University is 1 of the 2 universities of the State of Indiana. The schools of electrical, chemical, mechanical, and civil engineering, science, agriculture, home eco-

nomics and pharmacy are located in West Lafayette, while those of arts, law, and medicine are located at Indiana University at Bloomington, Ind. The 4 schools of engineering are housed in separate buildings, those of electrical and mechanical engineering being particularly new, of large size and well equipped with commodious laboratories. The broadcasting station, WBAA, with its studios, and the short-wave amateur station W9YB will be found in conjunction with the department of communication on the third floor of the electrical engineering building, while the rather unique television station, W9XG is located near the Ross Ade Stadium, $^1/_4$ mile north of the main campus.

TRANSPORTATION

It is expected that so many will travel by automobile that reduced railroad fares which are sometimes based upon a minimum number of certified railroad tickets will not be available. However, Lafayette, Ind., where the Fowler Hotel and Lahr House are located only one mile from the university in West Lafayette, may be readily reached via the Big Four, Monon, Nickel Plate or Wabash railroads. It is also located on national highways 52 and 152 between Chicago and Indianapolis as well as routes 25, 26, and 43 from east and west points.

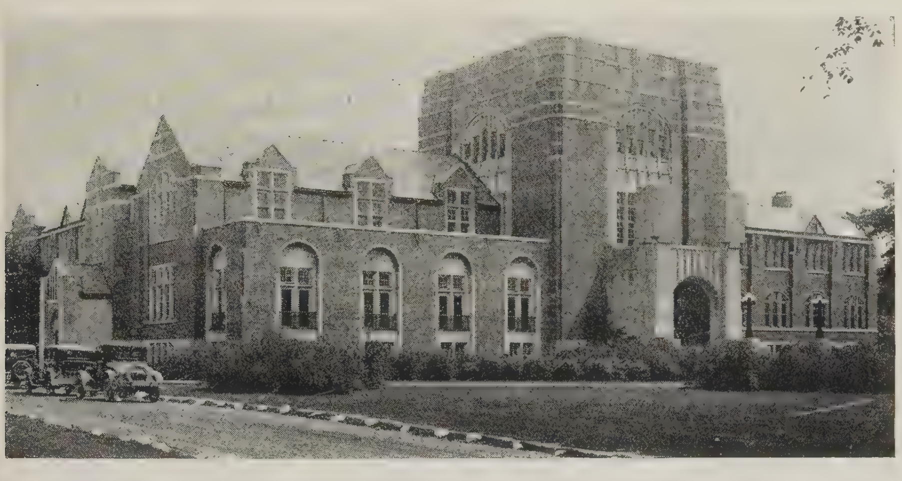
REGISTRATION

All who plan to attend this meeting are urged to register in advance by mail, if possible, by writing to J. H. Bowman, chairman, registration committee, Purdue University, West Lafayette, Ind. Members and guests should complete their registration as soon after arrival as possible so as not to miss the opening session on Thursday morning. There will be no registration fee for members of the Institute and their immediate families or for students. Nonmembers, not students, will be charged a fee of $2. Tickets for the dinner Thursday evening at $1.50, for the student luncheon Friday noon at $0.75, and for the football game Saturday afternoon ($2.25 reserved seats) should be secured at the registration desk to avoid later congestion and delay.

Hotel reservations should be made directly with the hotels, the rates per day being as follows:

	Single	Double
Fowler Hotel		
With bath	$2.50	$4.00 and up
Without bath	2.00	3.50 and up
Lahr Hotel		
With bath	2.00	3.50 and up
Without bath	1.50	2.50 and up

Although the hotel accommodations will be limited on Friday and Saturday nights on account of the homecoming football game, they should be adequate, if reservations are made in advance, for Wednesday and Thursday nights. An adequate supply of satisfactory rooms in private homes will be available also at the registration desk.



The Memorial Union or student building on the campus of Purdue University, West Lafayette, Ind., which will be a central point for social gatherings during the Institute's Great Lakes District meeting, Oct. 24–25, 1935. The Memorial Union building is near the university's electrical engineering building, in which the technical sessions will be held

COMMITTEES

General Convention Committee—G. G. Post, vice president, District 5, *chairman;* A. G. Dewars, secretary, District 5; C. A. Cora, F. R. Finehout, D. H. Hanson, C. F. Harding, O. Kiltie, E. B. Kurtz, G. V. Mueller, and A. N. Topping

Papers Committee—C. F. Harding, *chairman;* D. T. Canfield, C. A. Cora, D. L. Curtner, D. D. Ewing, F. R. Finehout, D. H. Hanson, O. Kiltie, E. B. Kurtz, G. V. Mueller, L. D. Rowell, C. S. Roys, and A. N. Topping

Attendance and Publicity Committee—D. L. Curtner, *chairman;* J. N. Arnold, J. H. Karr, W. A. Knapp, T. R. Johnston, and R. C. Woodworth

Student Session and Papers Committee—E. B. Kurtz, *chairman;* H. N. Hayward; C. C. Knipmeyer; E. E. Reynolds; E. M. Sabbagh; A. N. Topping, Purdue A.I.E.E. Branch chairman; R. B. Immel; R. L. Kessel, *vice chairman;* and R. V. Morris, *secretary*

Finance Committee—G. G. Post, *chairman;* G. V. Mueller, *local chairman;* K. A. Auty, C. A. Cora J. W. Esterline, and F. Holmes

Reception and Registration Committee—J. H. Bowman, *chairman;* L. E. Beck, J. H. Karr, and C. S. Siskind

Transportation, Demonstrations, and Inspection Trips Committee—D. D. Ewing, *chairman;* C. B. Aiken, C. W. Caldwell, K. F. Dickinson, R. H. George, S. Green, H. J. Heim, W. A. Knapp, B. H. Short, and C. S. Sprague

Entertainment Committee—(Dinner, luncheons, etc.) D. T. Canfield, *chairman;* J. Bixler, P. S. Emrick, and W. A. Knapp

Women's Entertainment Committee—Mrs. C. F. Harding, *chairman;* Mrs. Bixler, Mrs. Canfield, Mrs. Dickinson, Mrs. Ewing, Mrs. Green, and Mrs. Holmes

Student Entertainment Committee—A. N. Topping, *chairman;* H. R. Imle, R. B. Immel, R. L. Kessel, and R. V. Morris

Housing and Convention Hall Arrangement Committee—G. C. Blalock, *chairman;* J. W. Hammond, R. B. Marshall, J. W. Walker

Additional Awards for 1934 Institute Papers

In addition to the national and District prizes for papers presented before the Institute during the calendar year 1934, as announced in ELECTRICAL ENGINEERING for June 1935, page 677, and July 1935, page 785, announcement now has been made of the award of prizes for Districts Nos. 8 and 9. These awards are:

DISTRICT NO. 8

Prize for best paper awarded to A. A. Kroneberg (A'28, M'34) and Mabel Macferran Rockwell (A'28, M'35) for their paper "Power Limits of 220 Kv Transmission Lines," published in ELECTRICAL ENGINEERING for November 1933, pages 758–66, and discussed at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

Prize for initial paper awarded to F. C. Lindvall (A'26) for his paper "A Glow Discharge Anemometer," published in ELECTRICAL ENGINEERING for July 1934, pages 1068–73, and discussed at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

Prize for Branch paper awarded to D. R. Tibbetts (A'35) for his paper "San Francisco-Oakland Bay Bridge Construction Radiotelephone System," presented at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

DISTRICT NO. 9

Prize for best paper awarded to R. C. Hummel (A'29) for his paper "The Design and Operation of an Automatic All Relay Telephone Switching System for Small Communities," presented at a meeting of the Seattle (Wash.) Section, Feb. 20, 1934.

Prize for Branch paper awarded to K. M. Klein (A'35) and E. J. Harrington for their paper "The Influence of Ground Plane Proximity Upon the Polarity of Sphere-Gap Spark-Over," presented at a joint meeting of the Portland (Ore.) Section and Oregon State College Branch, May 19, 1934.

Future AIEE Meetings

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on August 6, 1935.

Present: *President*—E. B. Meyer, Newark, N. J. *Vice Presidents*—C. V. Christie, Montreal, Que.; Mark Eldredge, Memphis, Tenn.; R. H. Fair, Omaha, Neb.; W. H. Timbie, Cambridge, Mass. *Directors*—F. Malcolm Farmer, New York, N. Y.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation, I. Melville Stein, chairman, special committee on revision of Section territories.

The minutes of the meeting of the board of directors held June 26, 1935, were approved.

A report of a meeting of the board of examiners held July 24, 1935, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 10 applicants were elected and 19 were transferred to the grade of Member; 74 applicants were elected to the grade of Associate.

The finance committee reported disbursements for July amounting to $20,082.10. Report approved.

Proposed amendments to Sections 22 and 23 of the by-laws to bring them into conformity with the amendments to the constitution which were recently adopted by the membership were approved, subject to confirmation at the October meeting.

Announcement was made of the appointments by the president of Institute committees for the administrative year beginning August 1, 1935 (a list of the committees and representatives of the Institute appears near the end of the "News" section in this issue).

The board confirmed the reappointment by the president of C. E. Stephens as chairman of the Edison Medal committee for the year beginning August 1, 1935, and the appointment of the following members: F. J. Meyer, R. A. Millikan, and Marion Penn for terms of 5 years each; G. G. Post for the year beginning August 1, 1935, to fill the vacancy caused by President Meyer's becoming an *ex-officio* member; and Dr. H. S. Osborne for the unexpired term, ending July 31, 1937, of S. P. Grace (deceased). The board of directors elected from its own membership, to serve on the committee for terms of 2 years each, W. H. Harrison, C. R. Jones, and W. B. Kouwenhoven.

The appointment by the president of L. W. Chubb, N. E. Funk, and W. H. Harrison as members of the Lamme Medal committee for terms of 3 years each, and of A. M. MacCutcheon as chairman of the committee for the present year, was confirmed.

Special committees of the Institute were reviewed and reappointed. Representatives of the Institute on various bodies for the adminstrative year beginning August 1, 1935, were appointed.

C. O. Bickelhaupt (chairman, A.I.E.E. delegation), F. J. Chesterman, William McClellan, C. E. Stephens, and H. H. Henline (alternate) were reappointed representatives of the Institute on the Assembly of American Engineering Council for the year 1936. (The remaining member of the A.I.E.E. delegation, President E. B. Meyer, was appointed at the June board meeting to serve for the year August 1, 1935, to August 1, 1936.)

Prof. Charles F. Scott was reappointed a representative on the Engineers' Council for Professional Development for the 3-year term beginning in October 1935.

E. W. Rice, Jr., was reappointed a member of the Hoover Medal board of award for the six year term beginning in October 1935.

The following local honorary secretaries of the Institute were reappointed for terms of 2 years each beginning August 1, 1935: F. M. Servos, for Brazil; A.P.M. Fleming, for England; Renzo Norsa, for Italy; P. H. Powell, for New Zealand; A. F. Enstrom, for Sweden.

A progress report of the special committee on revision of Section territories was presented by Chairman I. Melville Stein, and was approved.

The board directed that suitable greetings from the A.I.E.E. to the Institute of Electrical Engineers of Japan be prepared, for conveyance by Dr. Dugald C. Jackson, who will lecture in Japan this fall under the auspices of the Iwadare Foundation.

Other matters were discussed, reference to which may be found in this or future issues of Electrical Engineering.

Membership—

Mr. Institute Member:

Most of the Section membership committees for the coming year have been formed and are already at work.

Your co-operation in the past in suggesting to the chairman of your Section membership committee the names of those who, you feel, are worthy to be invited to join the Institute has been of the greatest help and we are hopeful that it is becoming a part of your Institute thought to do this at every opportunity.

By doing your part during 1934–35 the membership committee was able to accept the bogey of more applications for membership in any month than in the corresponding month of the previous year, and to meet it in 11 of the past 12 months.

Everett S. Lee

Chairman National Membership Committee

Lightning Reference Book May Be Issued

Several orders have already been received for the proposed lightning reference book which was announced in Electrical Engineering for August 1935, page 907. This book, if issued, would include the full text and illustrations of most papers on the subject of lightning, published from 1918 to 1935 by the A.I.E.E., in addition to those published in the *General Electric Review*, the *Electric Journal*, *Electric World*, the *Journal* of the Franklin Institute, and perhaps the English translations of a half dozen or so of the more important foreign papers. A comprehensive cross-reference index of authors' names and paper titles would be included as part of the volume. In size, it would be similar to the A.I.E.E. Transactions, comprising some 1,300 9 by 12 inch pages, making a book about $2\frac{1}{2}$ inches thick.

The lightning and insulator subcommittee of the A.I.E.E. power transmission and distribution committee has carried on an extensive canvass of the literature on lightning and its effect on electric power systems and apparatus, and more than 250 papers and technical articles have been indexed. In these papers are considered lightning characteristics, theory, laboratory and field tests, and protective devices used and their application and performance.

In order that this information may be readily available to those interested, it is proposed that the volume now under consideration be compiled. Although several orders have already been received, the number of orders is not yet large enough to warrant issuing the volume. For the benefit of interested persons, a coupon that may be filled in and mailed at once is included on page 8 of the advertising section of this issue. (If a sufficient number of orders is not received promptly, the proposal will be dropped.)

The Institute's

Publication Policy and Services

A report on the publication policy of the Institute presented at the conference of officers, delegates, and members held during the recent A.I.E.E. summer convention at Ithaca, N. Y., June 24–28, 1935, by C. O. Bickelhaupt, chairman of the A.I.E.E. publication committee.

THE objects of the Institute are "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members." The publication service is one of the most useful and important means of accomplishing these purposes, and is a tangible record of service to the membership.

Historically, the publication procedure of the Institute may be divided into 3 distinct periods. Prior to 1920, 2 publications were issued to all members. Papers, discussions, and Institute news were published monthly in the PROCEEDINGS. Part of this material, together with some additional matter, was included in an annual bound volume designated as the TRANSACTIONS, which was regarded as the formal record of the Institute's technical activities.

The second period began in 1920 when the name of the monthly publication was changed to the JOURNAL with a change in format. Also, the TRANSACTIONS was removed from a general circulation basis and placed upon a nominal subscription basis that was intended to be self-supporting because it was expected that the TRANSACTIONS would continue to duplicate a large part of the material which it was planned to publish in the monthly. However, this period, which continued through 1930, saw an ever-widening difference in content between the JOURNAL and the TRANSACTIONS which, incidentally, was changed in 1928 from an annual to a quarterly publication. By 1928 the extent to which technical papers were published in the monthly had been reduced gradually until the JOURNAL content consisted principally of abridgments of technical papers. In the meantime, a supplementary service consisting of a wide and free distribution of individual pamphlet copies of technical papers had been made available to the membership. The thought there seemed to be that any member could secure pamphlet copies of those papers in which he was most interested, and that since this service was available it would be necessary to carry only abridgments of these papers in the JOURNAL for general circulation to the entire membership.

ELECTRICAL ENGINEERING INITIATED

The third period in the history of the Institute's publication policy was entered as the result of an extensive survey conducted by the publication committee during 1929–30. The monthly JOURNAL was changed beginning January 1931 to ELECTRICAL ENGINEERING, and the character and scope of its content was modified to meet the membership's indicated preference for a "more popular" monthly publication. This step, judging from the volume of correspondence received from members, met with wide approval.

However, with technical papers as then published in ELECTRICAL ENGINEERING reduced in many instances to abbreviated abstracts, the differences between the Institute's principal publications were emphasized and brought to a maximum. ELECTRICAL ENGINEERING was serving the demand for "popular material," the pamphlet service was attempting to meet the requirements for general distribution of complete technical papers, and the quarterly TRANSACTIONS was serving the triple rôle of record volume, purveyor of technical papers to those not receiving them in pamphlet form, and as the *only channel* through which discussions of technical papers were reaching *any* of the membership in printed form.

This publication procedure had its advantages, but it was developing rapidly into an exceedingly expensive program of publication, considering the service rendered. All papers involved the expense of double publication and many of them triple publication: first in pamphlet preprint form, then in the quarterly TRANSACTIONS, and in many instances also as rewritten for use in ELECTRICAL ENGINEERING. Finally, and in the face of impending heavy reductions in publication budgets necessitated by depression conditions and impaired income, it became evident that the amount of material published would have to be reduced drastically unless some simpler publication procedure could be developed.

UNIFIED PUBLICATION PLAN ADOPTED

Accordingly, to reduce costs while retaining the principal advantages gained through steady development, the publication committee and editorial staff again went exhaustively into the matter beginning in the fall of 1932. That effort led to the development and adoption of the so-called "unified publication plan" which, during the past 2 years, has resulted in greatly expanding the publication service to every individual member of the Institute, while at the same time permitting a reduction of 40 per cent in the publication budget as compared with that for the year 1930–31.

As now published, ELECTRICAL ENGINEERING and the annual TRANSACTIONS are identical. As a matter of production economy, the pages for the annual volume are printed month by month while the forms of the monthly publication are still on the presses, are accumulated during the calendar year, and issued at the end of the year as a complete reference volume covering the Institute's published technical material for the year. It is recognized that this simplified procedure may have some minor practical and theoretical disadvantages. However, its adoption has placed the TRANSACTIONS on a self-supporting basis for the first time, and has eliminated the inequities of an average annual deficit of some $17,000 which had to be borne by the membership at large for the benefit of those who received the TRANSACTIONS under the old publication procedure. Elimination of the costly process of attempting mass distribution of technical papers through the medium of pamphlet copies mailed to individual order, has resulted in an additional saving of some $7,500 per year. The expense of this special service, which was increasing rapidly, was by no means justified, being in effect a general assessment for a specialty service. Now, authors and others wishing reprints for special purposes are given the benefit of reprint service at actual cost.

As now published under the unified publication plan, ELECTRICAL ENGINEERING each month places in the hands of every member of the Institute (based upon the calendar year 1934, and *excluding* the special May 1934 anniversary issue) an average of:

77 pages presenting the full text of more than 12 A.I.E.E. technical papers.

14 pages conveying the full text of some 27 written discussions of A.I.E.E. technical papers.

Approximately 15 pages conveying 3 or more special articles on topics of timely general interest.

15 pages of news items covering Branch, Section, District, and other Institute activities, and miscellaneous items of current general interest.

The 199 pages of special material in the 50th Anniversary issue of ELECTRICAL ENGINEERING were published over and above the regularly scheduled material.

CO-ORDINATION OF PUBLICATION AND MEETINGS

It is of significance to note in this connection that all technical papers on national convention programs, and most technical papers on District meeting programs, have been published in full in ELECTRICAL ENGINEERING well in advance of the meetings, thus extending to every member the opportunity for participation in the discussion of each paper, whether in attendance or not. Further, this effective advance distribution of technical papers has materially relieved congestion at convention technical sessions by making possible immediate discussion of many papers without the necessity of taking time for oral presentation of the paper. Also, prompt publication and complete circulation has facilitated discussion of technical papers at District meetings in various parts of the country, giving the opportunity for active participation to more members, and making available to the membership at large a wider variety of thought on a given paper through the medium of subsequent publication of written discussions originating at such meetings. A good many Sections, too, have found technical discussion meetings built upon papers published in ELECTRICAL ENGINEERING to be an attractive supplement to regular Section meeting programs.

THE TRANSITION PERIOD

When the unified publication plan was recommended in June 1933 by the publication committee, it was on the basis of a publication schedule tentatively contemplating a transition from a post-publication to a pre-publication policy during a period

beginning with the July 1933 issue of Electrical Engineering and being completed by January 1935. That program was considered in order to provide time for necessary and desirable preliminary steps, in order to spread over a reasonable working period the tremendous burden of work involved in making such a major change in publication procedure, and in order to take advantage of a natural break in the yearly production program then prevailing.

However, under the pressure of economic conditions the transition was precipitated in the fall of 1933. It was undertaken "from scratch" in an effort to realize within some 6 months—instead of the 18 months originally planned—at least the essential improvements and major economies of the new program. This more than doubled the publication burden. Not only was it necessary to continue to satisfy commitments developed under the old publication program where the established procedure was to "reach back" to previous meetings for material for the monthly publication, but it was also necessary at the same time to "reach ahead" under the provisions of the new publication plan which contemplated advance publication of most technical papers. With the effective co-operation of the technical program committee which is responsible for the arrangement of national convention programs and the handling of the technical papers involved, the advance publication of all papers on the program of the then current winter convention was completed with the January 1934 issue of Electrical Engineering. Another year was required for the development of an even flow of new technical material as required under the new publication plan, and to work out other important problems involved.

The unified publication plan is now well beyond its transition stage, providing opportunity in line with original plans for the development of further and related refinements and improvements. This accomplishment is the result of many months of hard and continuous work on the part of the editorial staff. With unusual and difficult operating problems to handle, the staff has carried the burden of extra work involved in the transition to the unified publication plan only through contributing many hours of overtime to get the job done on time. The publication committee and the Institute owes a debt of gratitude for this loyal support.

It is the purpose of your publication committee and of the editorial staff to keep the policy and procedure governing the Institute's publications sufficiently flexible to meet the constantly evolving needs and desires of the membership, and so to develop the program and publications as may be necessary to serve as equitably, economically, and effectively as possible the tremendously wide range of interest of the thousands of members and Enrolled Students who are the American Institute of Electrical Engineers.

Student Convention Held by North Eastern District

The Student Branches of the Institute's North Eastern District, number one, held a convention at Rensselaer Polytechnic Institute, Troy, N. Y., on May 3 and 4, 1935. The student convention was held because there was no meeting of the North Eastern District this year on account of the holding of the summer convention at Cornell University, and this convention came after the school year was closed. Lodging was provided in the college dormitories at an extremely low rate.

Friday, May 3, was given over to an all day inspection of the Schenectady, N. Y., works of the General Electric Company. At the annual meeting of the Branch counselors and chairmen held that evening, the chairman and the committee members of the previous year were re-elected for the coming year. They are: W. B. Hall, Yale University, *chairman;* A. R. Powers, Clarkson College; and F. N. Tompkins, Brown University. At the evening meeting attended by all, E. O. Shreve, vice president of the General Electric Company, spoke on opportunities for the engineering graduate, and Mr. Darlington described and demonstrated vacuum tubes.

On Friday, May 4, in Sage Laboratory at Rensselaer, the following student papers were presented:

Induction Motor Control by a Thyratron Converter, S. B. Farnham, Yale University.

A High Sensitivity Vacuum Tube Voltmeter, W. R. Harry, Cornell University.

A Proposed Method of Increasing Signal to Noise Ratio in Radio Reception, D. B. Nason, University of New Hampshire.

A Study of the Tilt of Radio Wave Fronts, W. H. Davenport, and F. G. Webber, Worcester Polytechnic Institute.

Harmonic Operation of a Transmitting Antenna and Feeder System, W. B. Plummer, Union College.

Solution of Special Problems in Pipe Flow by Means of Analogous Electrical Circuits, D. J. Ball, Rensselaer Polytechnic Institute.

Beyond the Milky Way, T. N. Wilcox, Massachusetts Institute of Technology.

A New Reverberation Time Meter, L. H. Morrison, University of Maine.

Applications of the Thyratron Tube With a Floating Grid, H. L. Blaisdell, Rhode Island State College.

Construction and Study of an Artificial Telegraph Cable, F. W. Gullo and D. A. Day, Worcester Polytechnic Institute.

Nonlinear Resonant Circuits, K. N. Mathes, Union College.

Experimental Demonstration of Torque Inductance Relationship, R. Potter, Yale University.

The following prizes for excellence of presentation, offered by the North Eastern District, were awarded immediately at the close of the sessions.

First prize	$10	S. B. Farnham	Yale Univ.
Second prize	5	W. R. Harry	Cornell Univ.
Third prize	3	F. W. Gullo	Worcester Poly. Inst.

That evening there was a banquet in Russell Sage dining hall. The Institute prize of $25 for the best Branch paper from the North Eastern District written by an undergraduate, was awarded to Albert E. French, Clarkson College, for his paper entitled "The Place of Operational Calculus in Undergraduate Study of Electrical Engineering," which was presented a year previously at the District convention at Worcester, Mass. Stanley Pierce, a member of the Harvard Branch, gave an extremely interesting illustrated talk on his experiences as electrical expert with the latest Byrd expedition to Little America.

Attendance statistics are:

Clarkson Institute of Technology	9
Cornell University	20
Harvard University	1
University of Maine	8
Massachusetts Institute of Technology	6
University of New Hampshire	30
Rhode Island State College	10
Rensselaer Polytechnic Institute	51
Syracuse University	20
Union College	5
University of Vermont	21
Worcester Polytechnic Institute	31
Yale University	17
Total	229

Students 209 Faculty 20

The Purdue Campus, Location of a District Meeting

The campus of Purdue University as viewed from the air, spring of 1935. On this campus at West Lafayette, Ind., the meeting of the Great Lakes District of the A.I.E.E. will be held Oct. 24–25, 1935

Section Technical Committee

Activities of the Portland, Ore., Section

A report of the experiences with Section technical committees obtained by the Institute's Portland, Ore., Section during the past year, presented at the conference of officers, delegates, and members during the Institute's summer convention, Ithaca, N. Y., June 24–28, 1935, by John Bankus, chairman of the Portland Section for 1935–36, and secretary-treasurer for 1934–35.

THE matter of organizing technical committees in both Sections and Districts was discussed at considerable length at the Institute's 1934 summer convention at Hot Springs, Va. The chairman and executive committee of the Portland (Ore.) Section believed that the idea of establishing Section technical committees offered one of the most effective means for increasing the value of the Institute to the Section members. By means of a letter the chairman brought the matter to the attention of all members of the Section.

The executive committee of the Portland Section felt that as far as Portland is concerned the Section technical committees would function best if they were purely local in character without any connection with District or national technical committees.

The executive committee also felt that in organizing Section technical committees it would be advisable to start with not more than 3 committees, and after discussing the matter with interested members in the Section, technical committees were chosen on communication, industrial power applications, and transmission and distribution. These were selected because they appeared to have the greatest local interest. However, it was the executive committee's intention that additions or substitutions could be made as desired from time to time by the local membership.

The chairman of the different technical committees were chosen by the Section chairman. In appointing technical committee chairmen particular care was taken to obtain men who are not only competent but who are also greatly interested in the Institute and technical committee activities. The technical committee chairmen were made responsible for the programs and the proper functioning of their respective committees. However, notices of meetings were sent out by the Section secretary.

The carrying on of the local technical committee activities has not involved any large expense on the part of the Section. A comparatively small room is ample for holding these meetings. So far, through the co-operation of interested utility engineers and executives it has been possible to secure the use of a room with blackboard accommodations without charge. Notices of meetings are sent to all members and the expense of such notices is borne by the Section.

The programs for the past year have covered a wide variety of subjects, as will be seen by referring to tables I and II, which summarize activities of Section and technical committees. It will be seen from these summaries that the Section technical committees have contributed very materially to the year's activities of the Portland Section. For the 22 committee meetings, the total attendance was 352; when this is compared with the total attendance at the 9 regular monthly meetings of 639, the technical committee meetings are seen to have added some 55 per cent to the membership participation in the activities of the Section; it is of importance to note that different groups of members attended the meetings of the different committees, and that these members were largely in addition to those who attended the regular meetings. This increased activity in itself would amply justify the step which has been taken.

But the greatest benefit is believed to result from the effect which the technical committee activities have had on the membership, especially the younger members. These committee meetings have enabled a much larger number to participate in the Institute activities and there is a feeling on the part of the members that they are getting much more for their money.

The past year's experience of the Portland Section has shown that the technical committee activities afford an excellent opportunity for bringing out the talent which exists in the Section.

Table I—Regular Monthly Meetings

Date	Subject	Attendance
Sept. 17, 1934	Insulation and protection of transmission lines and stations; and multiple velocity theory of traveling waves	58
Oct. 16, 1934	Theory and construction of the expulsion oil circuit breaker	42
Nov. 27, 1934	Electric figures	127
Dec. 11, 1934	Construction features of Boulder Dam, power house, and 275 kv transmission line	80
Jan. 22, 1935	Transmission line studies for the Columbia River development	82
Feb. 26, 1935	Polarity characteristics of sphere gaps	60
Mar. 23, 1935	High voltage insulators and the A.I.E.E. tests	54
Apr. 22, 1935	Teletypewriter operation—transmission features	74
May 25, 1935	Joint meeting, Portland Section and Oregon State College Branch at Corvallis	62
Total attendance at regular meetings		639
Inspection Trips		
Dec. 8, 1934	Inspection of model of Bonneville project at government moorings	20
Apr. 22, 1934	Inspection of telegraph equipment in telephone building	74

Table II—Local Section Technical Committee Meetings

Date	Subject	Attendance
Industrial Power Application Committee		
Oct. 22, 1934	Fundamentals of electronic tubes	14
Oct. 31, 1934	Fundamentals of electronic tubes	16
Nov. 14, 1934	Fundamentals of electronic tubes	16
Nov. 28, 1934	Fundamentals of electronic tubes	15
Dec. 19, 1934	X ray apparatus with inspection of Westinghouse X Ray Lab	18
Jan. 9. 1935	Theory and application of photosensitive devices	17
Jan. 30, 1935	Industrial application of photoelectric tubes	19
Mar. 13, 1935	Conference on industrial operating problems (4 subjects)	20
Apr. 15, 1935	Conference on industrial operating problems (10 subjects)	22
Subtotal		157
Communication Committee		
Oct. 29, 1934	Problems involved in the construction of new transmitters for KOIN and KALE	18
Nov. 19, 1934	Theory of coaxial lines	15
Dec. 17, 1934	Vacuum tubes as high frequency oscillators	16
Jan. 21, 1934	Telephone and radio communication in the forest service	20
Mar. 18, 1935	Problems pertaining to program switching and studio technique	14
Apr. 21, 1935	New theories of detection and rectification of radio frequencies	12
Subtotal		95
Transmission and Distribution Committee		
Oct. 8, 1934	General features of Bonneville Dam	13
Nov. 5, 1934	Demonstration of oscillograph used for analyzing electrical apparatus phenomena	17
Dec. 10, 1934	Market possibilities for Bonneville power	20
Jan. 14, 1935	Developments in overhead and underground network protectors	15
Mar. 11, 1935	Electricity goes to sea (films)	14
Apr. 8, 1935	275 kv impulse oil circuit breakers for the Boulder Dam, Los Angeles line	13
May 27, 1935	Experiences with electrical installation at Dnieperstroy	8
Subtotal		100
Total attendance at all committee meetings		352

Student Conference Held by North Central District

The 8th annual conference of student Branches of the Institute's North Central District, number 6, was held at North Dakota State College, Fargo, April 12–13, 1935. There was a total registered attendance of 83, which included, in addition to R. B. Bonney, vice president of the North Central District, and W. G. Rubel, secretary of the District, the following student counselors and Branch chairmen:

Counselor	Branch Chairman	Institution
H. S. Rush	Ted Peterson	No. Dak. State Col.
F. W. Norris	E. G. Guenzel	Univ. of Neb.
R. E. Nyswander	W. A. McWhorter	Univ. of Denver
H. F. Rice	E. L. Johnston	Univ. of No. Dak.
B. B. Brackett	Geo. Fullencamp	Univ. of So. Dak.
G. H. Sechrist	Henry Crabtree, Jr.	Univ. of Wyoming
	R. C. Davidge	Univ. of Colo.
W. H. Gamble	Evan Jensen	So. Dak. State Col.

Sessions were held on Friday afternoon and on Saturday morning, and on Friday evening a banquet was held. A meeting of the student Branch counselors was held after the Saturday morning session.

The program for the Friday afternoon and Saturday morning sessions was as follows:

Address of Welcome, President J. H. Shepperd, North Dakota State College; with response by R. B. Bonney.

Selective Admission of Students to Engineering Colleges, Prof. H. F. Rice, University of North Dakota; discussion by George Fullencamp, University of South Dakota, and Henry Crabtree, University of Wyoming.

Is the Engineering Curriculum Too Technical? Prof. F. W. Norris, University of Nebraska; discussion by Evan Jensen, South Dakota State College, and E. L. Johnson, University of North Dakota.

The Effect of Government Ownership of Public Utilities on the Engineering Profession, Prof. W. C. DuVall, University of Colorado; discussion by Ted Peterson, North Dakota State College.

Democracy Challenged, Dean A. E. Ninard, North Dakota State College

Engineering and the High School Senior, Prof. R. E. Nyswander, Denver University; discussion by R. C. Davidge, University of Colorado.

Should Engineering Graduates Look to Large or Small Companies for Work in the Future? Prof. J. O. Kammerman, South Dakota State School of Mines; discussion by Prof. W. H. Gamble, South Dakota State College.

A Demonstration of High Frequency Fever Machine, Foster Buck, North Dakota State College.

Will There Be Fewer Opportunities for Electrical Engineering Graduates in the Future? Prof. G. H. Sechrist, University of Wyoming; discussion by W. A. McWhorter, Denver University.

On Friday evening the delegates and some 65 other guests were entertained at a banquet and program given by the North Dakota State College Branch in the Waldorf Hotel in Fargo. The program was presided over by Ted Peterson, chairman of the local student Branch; Wesley Gilbertson and Harold Naegeli, both of this Branch, furnished entertainment. The address of the evening was given by R. H. Fair, recently elected vice president representing this District, on the subject of "Some Aspects of the Art of Utilizing Engineering Knowledge." Remarks of Dean R. M. Dolbe, of the school of engineering of North Dakota State College, brought the evening program to a close.

Counselor Meeting

Chairman H. F. Rice called the meeting of the District committee on student activities to order, and after conducting some preliminary business, the question of location of the next conference was opened. A motion that the 1936 conference be held at the University of Colorado, at Boulder, was carried. Prof. W. C. DuVall of the University of Colorado was elected chairman of the committee on student activities for the ensuing year, and Prof. R. E. Nyswander of the University of Denver, was elected alternate. Following a brief discussion on the matter of stimulating more competition for the District prize for Branch papers, the meeting was adjourned.

Gustav Lindenthal, Bridge Engineer, Dies

Gustav Lindenthal, dean of American bridge engineers, died at his home in Metuchen, N. J., on July 31, 1935. His best known works are the arch bridge of the New York Connecting Railroad over the East River at Hell Gate, New York, N. Y., and the Sciotoville continuous bridge over the Ohio River, near Portsmouth, Ohio.

Doctor Lindenthal was born at Bruenn, Czechoslovakia, May 21, 1850, and came to the United States in 1874, joining the designing force of the Centennial Exposition at Philadelphia, Pa. In 1877, he went with the Keystone Bridge Company at Pittsburgh, Pa., and the following year became bridge engineer for the Atlantic and Great Western Railway at Cleveland, Ohio.

In 1881, he undertook private practice as a consulting engineer in Pittsburgh, Pa., and designed several bridges in that city, and other parts of the United States. In 1892, he moved to New York, N. Y., continuing his private practice, and designing several well known bridges. In 1902, he was appointed commissioner of bridges of New York City, and under his administration the Queensboro Bridge was designed. During this period, he also was a member of the board of engineers of the Pennsylvania Railroad tunnel in New York City. Doctor Lindenthal was chief engineer of the Hell Gate Bridge, 1907–17, and of the Sciotoville railroad bridge 1914–17.

A decade later, when Lindenthal was more than 75, he undertook a large public bridge program at Portland, Ore. In addition to his work on bridges, he served as designer or consultant on a number of important tunnel, dock, and terminal problems. Doctor Lindenthal had long given special consideration to the architectural aspects of bridges.

He had received the honorary degree of doctor of engineering from 3 institutions in Europe, and had received several prize awards in the United States. He was an honorary member of the American Society of Civil Engineers, and of other organizations in the United States and abroad.

Los Angeles Aqueduct Builder Dies

William P. Mulholland, nationally known hydraulic engineer and builder of the Los Angeles-Owens River aqueduct in California, died at Los Angeles, Calif., July 22, 1935. Doctor Mulholland was born in Belfast, Ireland, September 11, 1855, and came to the United States in 1872. From 1886 until his death he was with the Bureau of Water Works and Supply of the city of Los Angeles, Calif., as chief engineer and general manager. The work for which he was the best known was the construction of the Los Angeles-Owens River aqueduct which was built by the Bureau of Water Works and Supply, at a cost of $24,500,000, for bringing water 250 miles to the city from the Sierra Nevada Mountains, north of the city.

Doctor Mulholland also was one of the pioneer backers of the Boulder Dam project and did much of the preliminary work in connection with the $225,000,000 Colorado River aqueduct project of the Metropolitan Water District of Southern California, now under construction. In October 1923, he began surveys of possible routes for an aqueduct from the Colorado River; in 1928 the results of his studies were turned over to the Metropolitan Water District, formed in that year to carry out southern California's Colorado River water supply project.

He also was a consulting engineer, specializing in water supply and irrigation problems, and was chief engineer of the department of public service of the city of Los Angeles. He was educated in the public schools of Belfast, Ireland, and the Christian Brothers College in Dublin; in 1914, the University of California conferred upon him the honorary degree of doctor of law. He was a member of the American Society of Civil Engineers.

Member-for-Life List Brought Up to Date

Membership for life is granted by the Institute for either of the following 2 reasons: a member has attained a term of membership of 35 years; or has reached the age of 70 and has attained a term of membership of 30 years.

One feature of the 50th anniversary (May 1934) issue of Electrical Engineering was the inclusion on page 825 of a list of all members who had been on the Institute's rolls for 35 years or more. While each member on this list was obviously a member-for-life, the list did not include every one who was a member-for-life at the time of that issue, as there were a few who had become eligible under the second classification.

The list which follows includes all those who have become members-for-life under this second classification during the past 5 years, as well as all those who became members-for-life on May 1, 1935, by virtue of having attained a membership term of 35 years. This list, together with the list given on page 825 of the May 1934 issue of

Electrical Engineering, therefore includes all present members-for-life, regardless of classification:

Name	Date of Election	Eligible May 1
Abbott, W. L.	Oct. 25, 1901	1932
Atkins, C. G.	Oct. 25, 1901	1935
Barnes, H. H.	Feb. 28, 1900	1935
Barton, P. P.	July 12, 1900	1935
Beran, T.	July 25, 1902	1933
Blackwell, F. O.	Mar. 28, 1900	1935
Bowie, A. J.	May 15, 1900	1935
Bullen, D. R.	Mar. 28, 1902	1935
Cole, G. M.	July 25, 1902	1933
Dolph, J. C.	Sept. 25, 1903	1935
Dysterud, E.	July 26, 1900	1935
*Ensign, O. H.	Dec. 23, 1904	1935
Esterline, J. W.	Mar. 28, 1900	1935
Fish, F. A.	Mar. 28, 1900	1935
Fisken, J. B.	Apr. 24, 1903	1933
Gibbs, George	Apr. 28, 1905	1935
Hanscom, W. W.	Apr. 25, 1900	1935
Hawkins, C. C.	Nov. 20, 1903	1934
Imlay, L. E.	July 26, 1900	1935
Jacobus, D. S.	Sept. 25, 1903	1934
Kelsch, R. S.	May 20, 1902	1932
Lafore, J. A.	May 15, 1900	1935
Lundy, A. D.	Feb. 27, 1903	1933
McGraw, J. H.	Sept. 27, 1901	1932
Mixer, C. A.	Sept. 25, 1903	1934
Mortimer, J. D.	Mar. 28, 1900	1935
C. T. Mosman	Mar. 29, 1895—resigned May 1898; re-elected May 19, 1903	1935
Murphy, John	May 15, 1900	1935
O'Reilly, A. J.	Apr. 24, 1903	1933
Perkins, C. A.	Feb. 24, 1905	1935
Powelson, W. V.	Jan. 24, 1900	1935
Putt, Harvey I.	Mar. 27, 1903	1933
Russell, C. J.	Nov. 25, 1904	1935
Slichter, W. I.	Apr. 25, 1900	1935
Smith, E. A.	Dec. 18, 1903	1935
Smith, W. E.	Feb. 28, 1900	1935
Spencer, Thomas	May 19, 1903	1933
Steele, W. D.	Apr. 25, 1900	1935
Stevens, Theodore	Oct. 27, 1905	1935
Strong, J. R.	Mar. 22, 1901	1932
Sunny, B. E.	Feb. 27, 1903	1933
Thaler, J. A.	July 28, 1903	1935
Town, F. E.	May 15, 1900	1935
Turner, H. W.	Nov. 20, 1903	1934
Wallau, H. L.	May 15, 1900	1935

* Deceased June 1, 1935.

New Name Suggested for Mercury Vapor Converters

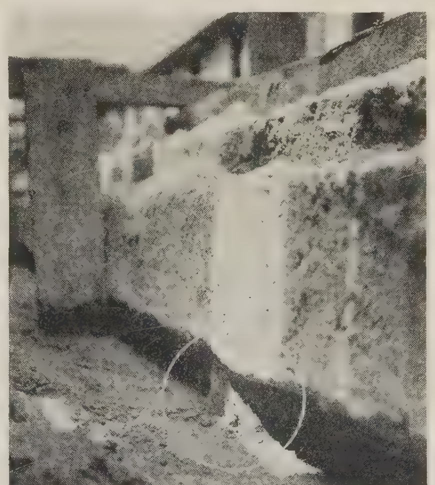
The word "mutator" has been proposed by Brown Boveri and Company, Ltd., Baden, Switzerland, as a general term to be applied to all forms of mercury vapor converters, with suitable adjectives to be applied to differentiate between rectifiers, inverters, frequency changers, etc. (For example, rectifiers might be called "ac-dc mutators," and converters might be called "dc-ac mutators.") The universal use of an accepted word such as "mutator" which is derived from the latin mutare (to alter, transform, change) and which might be used in all languages, is specially desirable to this company because its business is carried on in so many different countries. Other designations such as a valve, thyratron, etc., have the disadvantage of not being directly translatable into other languages, as is the case for such words as transformer, motor, generator, and regulator.

As an experiment, the Brown Boveri company introduced the word "mutator" in its December 1934 issue of *The Brown Boveri Review.* Informal inquiry seems to indicate that some commonly applicable term might find considerable favor in the United States, and the company's experiment in coining the new term will be watched with interest. The company reports that the word has been well received in England, especially in educational circles, and that the 2 most important engineering bodies in the Union of South Africa have adopted the term for exclusive use.

Comments of members of the Institute regarding use of the word "mutator" will be welcomed.

Ice an Unusual Aid in Construction Job

The problem of lowering concrete cable ducts a distance of nearly 2 feet, made necessary by regrading of a street surface in Brooklyn, N. Y., was recently solved in an unusual way by engineers of the Brooklyn Edison Company. In order to save the costly replacement of 2,700 feet of the duct and avoid interruption of service to Floyd Bennett Airport, the duct was lowered to its new position by the melting of cakes of ice. Under the direction of George W. Rainforth, supervisor of the subway bureau of the distribution department of the company, the first 300 foot section, weighing 64 tons, was lowered by means of 40 cakes of ice. The duct was uncovered for its entire length, and at 8 foot intervals undermined to insert the ice in cakes 21 inches high, half



A section of a 300 foot concrete duct line being lowered by ice, a block of which is shown (in circle) encased in sand to insure even melting

the size of the ordinary commercial cake. The remainder of the duct line was then undermined, and the ensuing exchange of thermal units lowered the concrete gently and evenly. Although not the first time ice has been used as a jack, it is rare that a job presenting such difficulties is consummated so expeditiously and inexpensively.

50th Anniversary of First A-C System in America

At the meeting of the board of directors of the A.I.E.E. held August 6, 1935, in Institute headquarters, New York, N. Y., the following self-explanatory resolution was adopted:

Whereas, on March 20, 1886, the first commercial alternating current electrical system was put into operation by William Stanley, at Great Barrington, Mass., and

Whereas, next March marks the fiftieth anniversary of the establishment of the alternating current system in America, be it

Resolved: That the American Institute of Electrical Engineers sponsor a suitable national celebration of this fiftieth anniversary of the alternating current system, and that the President be empowered to appoint a national committee to initiate and carry out this proposal.

Although plans have not yet been made, this coming memorial may possibly take the form of a large meeting in New York, N. Y., with broadcasting to each Institute Section. It will stress the 50th anniversary of the a-c system in the United States. It is of interest to note that a celebration of the 25th anniversary of the first commercial a-c electrical system in the United States was held by the A.I.E.E., Pittsfield, Mass., Section in 1911.

Thomas Alva Edison Foundation Is Incorporated

The Thomas Alva Edison Foundation has been incorporated for the purpose of creating a living tribute to the inventor whose genius gave to the entire world the first practical incandescent lamp and the phonograph; a major contribution to the electrification of industry and the home; inventions affording education, entertainment, and amusement to countless millions through the medium of motion pictures and radio; whose efforts improved telegraphy and perfected the telephone transmitter and in many other ways greatly benefited mankind.

The charter, filed under the membership corporation laws of the State of New York, provides a wide range of activity in which education is to play an important part.

It has "for its particular objects the advancement and diffusion of knowledge in the fields of physics, chemistry, and the engineering arts and sciences, both basic and applied."

Conceived by the Edison Pioneers, a body of co-workers with the inventor, and the A.I.E.E., and with the approval of the Edison family, the Thomas Alva Edison foundation is to carry out plans to perpetuate recognition of the world's progress emanating from the enventor's efforts.

Incorporators of the foundation are: William S. Barstow (A'94, M'99, F'12, and Life Member), president of the Edison Pioneers; Howel H. Barnes, Jr. (A'00, F'13, and past vice president); L. W. W. Morrow (A'13, F'25, and director), editor of the *Electrical World*, and Chas. F. Scott (A'92, M'93, F'25, HM'29, member for life and past-president), professor emeritus of electrical engineering at Yale University, representing the A.I.E.E.; and W. S. Mallory and F. A.

Scheffler (A'93, F'12, and member for life), representing the Edison Pioneers.

Mr. Barstow, in releasing announcement of the Foundation's incorporation, said: "It is planned by directors of the Edison Foundation properly to recognize the debt of the world to Edison's memory and to secure a fund with which to put this recognition into concrete form. What better or more timely task could be undertaken than one in which the focus of the entire world may be centered upon the works and memory of a man whose light now shines throughout the civilized universe: The week of October 21, 1935, is to be the starting point for nation-wide efforts to obtain such a fund. As the entire cost of the campaign itself will have been underwritten by friends of the inventor, every dollar thus secured is to be placed to the credit of the Thomas Alva Edison Foundation. One of the aims of the Foundation is to continue and perpetuate Edison scholarships, initiated by Mr. Edison, for the better preparation of American youth along technical educational lines."

American Engineering Council

New Service Initiated by A.E.C.

American Engineering Council is undertaking a new service for the benefit of the national, state, and local societies which hold membership in A.E.C., this service having for its purpose the aiding of the societies in their public affairs, public relations, and allied activities. It supersedes the supplement for state and local societies previously issued with its monthly "News Letter." Council states that the reason for assuming this responsibility is that it is anxious to do everything possible, within its limitations, to aid the affiliated societies with their social, economic, and political problems, in addition to co-operating with the national societies in their technical and professional activies.

This new service is designed for the exclusive use of member societies. For the benefit principally of state and local societies, secretaries of these societies are being extended the new service with the hope that they will find means to advise their members promptly regarding this information. Council suggests that this service be kept in a permanent file and that the members be notified as to its location and given free access to it.

The "News Letter" will continue to report the news of Council and to summarize the general news of interest to engineers, as of the 15th of each month, but the new service will be undertaken semi-monthly. Council welcomes suggestions for the improvement of its news services.

The first issue of this new semi-monthly service, dated August 15, 1935, summarizes the latest rules and regulations of a number of those government agencies entering the $4,880,000,000 work relief program of the federal government. Among the government agencies considered are the Works Progress Administration, Public Works Administration, Civilian Conservation Corps, Resettlement Administration, Federal Housing Administration, National Resources Committee, Public Health Service, National Youth Administration, and new census projects.

The accompanying item regarding the Engineers' Club of St. Louis also was abstracted from the first release of Council's new service.

Activities of the Engineers' Club of St. Louis

American Engineering Council reports that in the July 1935 issue of the *Journal* of the Engineers' Club of St. Louis, Mo., a well rounded picture of local club activities is presented. Of the 825 members of the Engineers' Club of St. Louis, 200 are serving on standing committees. It is stated that the club is the only engineering society in the United States that publishes a pictorial yearbook; for the 1935 number more than 95 per cent of the members furnished their photographs. A free employment service is maintained for all engineers in metropolitan St. Louis. An engineering library is owned by the club and is under the custody of the St. Louis Public Library. A membership card enables an engineer to draw books.

In 1926, the industries of St. Louis contributed $10,000 to the club's building fund, because they considered the club a character building enterprise, especially for the younger members in their engineering departments. Membership in the club, which felt the inevitable losses since 1929, practically held its own last year and is expected to increase through 1935. The membership committee is organized into a series of "baseball teams" whose competitive "batting averages" are reported each month. The club has no written rules governing the conduct of its members in the club building; the decision was to handle abuses when they arose, and none have arisen.

Competition and duplication of efforts between the club and local sections of national societies are eliminated under the policy that the advancement of engineering as a science be left to the national societies, and that the principal function of a local club is to devote its energy to the welfare of the members of the profession.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Registration of Engineers

To the Editor:

No one who heard Dr. D. B. Steinman's address on "Registration of Engineers" presented at the education session of the Institute's 1935 summer convention (and published in full in ELECTRICAL ENGINEERING for August 1935, pages 876–81) can escape one conclusion, *viz.:* the utter futility of debate as to whether or not registration should be. The fact that 31 states have accepted as essential the protection of the public against incompetence and fraud, and to that end have enacted measures providing for registration, is basic so far as registration per se is concerned.

There may be profit, however, in analyzing this legislation to determine its probable effectiveness and the extent and manner in which it affects the profession. If this analysis should make evident that in some particulars its effect on the profession is adverse, and if, without interfering with the stated purpose of the legislation, these factors can be modified, it would seem desirable to determine the procedure best suited to the obtaining of such modification.

Certain characteristics are essential to the success of regulatory legislation of this type. Primarily, it must meet a public need of sufficient importance to induce active enforcement. Secondarily, it must be so drawn as to interfere in the minimum degree with the reasonable operations of those whom it regulates.

If its provisions extend beyond what is necessary to the public need, or if it commands the support of only a fraction of those whom it affects, its modification or ultimate abandonment confidently may be predicted.

Dr. Steinman, an ardent advocate of registration, would have us believe that the very future of the profession lies in the extension and enforcement of such enactment and that only therethrough can the standing and standards of the profession be established and maintained. If he is right the question is one of major importance.

Present Extent of Registration

It is perhaps fortunate that the procedure has been in effect sufficiently widely to permit the gathering of some facts as to the extent to which the profession has arrayed

itself under the legislation, whether voluntarily or by enforcement.

In November 1934 American Engineering Council analyzed the 1930 census. 226,000 listed themselves as engineers. 214,000, or 95 per cent, were in the fields of civil, mechanical, and electrical engineering; 102,000 in the first and 112,000 in the other 2. The paper states that 85 per cent of the engineer population (or 192,000) are located in the 31 enacting states. It gives the number registered as 45,000, only 24 per cent of those affected.

The census recorded 44,400, or 44 per cent, of the civil engineers as exercising the relation in which the public needs to be protected, and 29,200, or 26 per cent, of the mechanical and electrical engineers. Of the total, 73,600, about 34 per cent, are in this relation. The total registration, therefore, is only 73 per cent of those registrable and listed as offering their services for hire or in public employment. Actually the fraction is less, since it is known that the registration includes many in private relation.

It would not appear from the above that registration has been adopted enthusiastically by the profession as a whole, nor even by those of the profession who are in that public relation whose control is the purpose of the legislation.

Equally, it would not appear that any measures of enforcement adopted had been outstandingly effective. For instance, the paper cites 348 violations—varying in character—as having received determinative consideration and of these 322 in the single state of New York. Undoubtedly there were more, but compared with the numbers involved almost any reasonable figure would be a negligible fraction.

Some Provisions of the "Model Law"

Obviously, there must be reason for this attitude. May it not be found in the probable effect of the legislation on the 66 per cent of the profession who are in private employment, as distinguished from the 34 per cent who occupy a public relation? Examination of the "model law" may provide some light.

Provisions which deny to qualified engineers the right to use the title of engineer in transactions which in no substantial degree affect the public interest, will surely not command the support of the individuals concerned. Yet these are the underlying bases of the "model law" and of much of the legislation.

Provisions that would compel the licensing of every member of the engineering staff of a corporation, irrespective of actual need, will surely not command the support of either the engineers involved or of the corporation. Yet this procedure is advocated.

The legislation to be practical must command extended respect and support. It must accomplish the actual need and attempt no more. That actual need is the protection of the public against incompetence and fraud. Whatever advantage the profession may gain must be incidental to this purpose.

That advantage will largely accrue to those members of the profession who offer their services to the public on a fee basis, or those in public employment: federal, state, and municipal.

The advantage to those in private employment is at least problematical. Registration will not increase their compensation. This will be based upon no formal standards, however authoritatively adopted, but on the employers' intimate knowledge and estimate of capability and desirability. The standards can take no cognizance of qualifications other than engineering per se. They are necessarily confined to the minimum qualification for the title. In fact, such men are actually handicapped. The effect of the legislation (using the "model law" to illustrate) is to forbid use of the title "engineer" to any unregistered or unlicensed person; this, whether or not he has public contact or responsibility and even though an acknowledged leader in the profession.

An engineer, formally "certified into the profession" under procedure now contemplated by the Engineers' Council for Professional Development (E.C.P.D.) would risk fine and imprisonment by unlicensed use of the title. Such a privately employed "certified" engineer could not use the title in contact or correspondence with his employer's customers, even though they are fully satisfied of his competency. And he must be licensed not merely in his own state but in that of the customer. A traveling engineer must be licensed in each state he visits. State reciprocity is hoped for but not achieved. A research engineer whose work is wholly within walls must be licensed. There is no differentiation between those offering their services to the public for hire and those who have no public function. The unwarranted cost and the handicaps involved are obvious.

In this respect the legislation differs from that of other professions. In law and in medicine it is directed to persons engaged in those occupations for hire and who offer their services to the public.

Fees and Costs of Registration

As to fees: The paper states that fees for the original registration certificate vary from \$5 to \$25. Figures given for 26 states in an analysis made by Western Society of Engineers indicate 16 states as requiring \$25, 3 states \$20 and 7 states \$15. Of the 6 of the above 26 states which include the major engineering population, 4 require \$25, 1—\$20 and 1—\$15. The "model law" suggests \$25.

A fair average would probably be \$20. This also is indicated by a suggestion of state acceptance of a \$10 fee when an additional \$10 fee has been paid to a central examining agency.

The paper gives renewal fees correctly in substance as ranging from \$1 to \$5. From the same analysis it appears that 1 state requires \$10; 12—\$5; 2—\$3; 2—\$2.50; 4—\$2; and 5—\$1. Five of these \$1 states are included in the 6 with major engineering population; the sixth requires \$5. A fair average might be of the order of \$3.

The paper speaks of the cost as small. Is it so small? Assuming the above figures and a final registration of only $^1/_2$ of the 226,000 recorded in the 1930 census, the states will collect from the profession \$2,260,000 for initial fees and \$339,000 annually for renewals. And this covers only licensing in the registrant's home state. The amounts will be increased by the multiple licensing essential to many.

But fees alone may not measure the total cost. The paper expresses its belief that the profession needs to "make its influence felt in legislative councils." This can be done only by country-wide organization, if undertaken systematically, and funds will be required. Furthermore, there is no evidence that the present enforcement measures are effective, and more drastic ones may well be instituted. If they are employed, fees will surely not diminish.

The paper expresses the belief that in time legislators will be educated to appreciate that at least half the total cost of registration should be contributed by the state, since the law is primarily for the protection of the public. Is this not, perhaps, slightly too optimistic?

Is there not also perhaps too much of optimism in anticipating any general acceptance of that provision of the "model law" (section 9) requiring that all funds derived from registration shall be isolated and used solely to advance the purposes of the law? This is contrary to the fiscal policy of some states and the paper indicates none in which it is in effect. On the contrary New York made a profit of \$300,000, Colorado established an engineering reference library from surplus, and Oregon's attorney-general approved an advertising campaign.

As the paper states, the fees are not intended as a source of revenue for the states, but so long as legislators are human this factor will probably not be absent.

State Boards of Registration

As to state boards of registration: The "model law" (section 3) provides most admirably for appointment by the governor from nominations made by representative engineering societies. But these positions carry compensation. Clerical and other assistants must be hired and expense incurred and reimbursed. Is one cynical in believing that there will be reluctance on the part of the practical politician in incorporating the provision? Turn then to the record.

But 2 states—Louisiana and Wisconsin—require nomination by engineering societies. Fifteen states leave appointment with the governor with provisions as to minimum age, registration, length of practice and diversification. Five add to these provisions only the requirement of membership in good standing in a recognized engineering society. Three leave appointment to state agencies other than the governor and one provides no method of appointment. Incidentally, there is no definition of "recognized engineering society."

Whatever may be the intent, is there such probability of the maintenance of a plane of service and ideals by boards so appointed as to warrant the transfer to them of the duty of establishing and enhancing the standards and the dignity of the profession?

Procedures Open to Engineers

Dr. Steinman may be right in saying that registration is the only means whereby legal force and sanction can be applied to certain problems of the profession, but is he right in implying that only therethrough

can the dignity of the profession be maintained and the public impressed with the fact that engineering is a learned profession?

Cannot the profession, by procedure of its own, evolve the minimum standards which are in its opinion necessary to the title of engineer, and can it not devise means for according that title to those who meet those standards and withholding it from those who do not?

Such standards would be prepared with registration constantly in view and probably co-operatively with the designated authorities. Standards so prepared would be almost automatically accepted and would be a major contribution to uniformity. Equally, they would be permanently without the field of politics.

When accorded the title of engineer should not the recipient (save when he offers his services to the public for hire) be left free to determine for himself the desirability of registration?

If this is the desirable condition, changes must be induced in much existing enactment. The first step in such a procedure would seem to be so to modify the "model law" as to assure for it the support of all elements within the profession. These modifications should be conceived with but a single purpose, *viz:* the adequate protection of the public against incompetence and fraud. There should be no attempt to bring within the law those whose registration is not essential to that purpose. Subject to these fundamentals they should be so drawn as to reflect practical considerations as exemplified in the legislation thus far enacted.

The "model law" brings within its scope all persons who do any of the things included within the definition of professional engineering, even though they do it without compensation. It provides:

> That in order to safeguard life, health, and property, any person practicing or offering to practice the profession of engineering***** shall hereafter be required to submit evidence that he is qualified so to practice and shall be registered as hereinafter provided; and it shall be unlawful for any person to practice or offer to practice the profession of engineering,***** in this state, or to use in connection with his name, or otherwise assume, use, or advertise any title or description tending to convey the impression that he is a professional engineer******, unless such person has been duly registered or exempted under the provisions of this act.

Section 2 defines the term "professional engineer" as one who is qualified to engage in engineering practice. It then defines engineering practice in detail, but with complete omission of any reference to holding one's self out to the public for hire as a professional engineer, thereby including all qualified engineers.

Section 17 provides that corporations, etc., may practice professional engineering only if such practice is carried on by registered engineers.

It exempts, section 20 (*c*), an employee or a subordinate of a person holding a certificate of registration "provided his practice does not include responsible charge of design or supervision." By inference it does not exempt such an employee or subordinate if the practice is consultation, investigation, evaluation, or planning—only design or supervision.

Unless some modification is made it would appear to be impossible for anyone not now meeting the requirements for a licensed engineer ever to become one. The law requires 4 or more years of active practice. The candidate cannot individually practice engineering without a license, the employer can use only licensed engineers and "the mere execution, as a contract, of work designed by a professional engineer, or the supervision of the construction of such work as a foreman or superintendent shall not be deemed to be actual practice in engineering work." (*Model Law*)

These provisions should be clarified to express accurately the intent, but one thing seems evident: The title "engineer" may not be used by anyone save under registration. Naturally the exemptees are debarred.

Surely the desire of the profession and of the individual will be that the title be employable, once qualification has been established, and subject only to the purposes of the legislation.

This clarification would result if the sections were reworded somewhat as follows:

> *Section 2. Definitions.* The term "professional engineer" as used in this Act shall mean a person who, by reason of his knowledge of mathematics, the physical sciences, and the principles of engineering, acquired by professional education and practical experience, is qualified to engage in professional engineering practice as hereinafter defined and holds himself out to the public for hire as practicing professional engineering.
>
> The practice of professional engineering within the meaning and intent of this Act includes any professional service to the public for hire, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction or operation, in connection with any public or private utilities, structures, buildings, machines, equipment, processes, works, or projects, wherein the public welfare, or the safeguarding of life, health or property is concerned or involved, when such professional service requires the application of engineering principles and data.
>
> *Section 17. Firms, Partnerships, Corporations, and Joint Stock Associations.* A firm, or a co-partnership, or a corporation, or a joint stock association may engage in the practice of professional engineering in this State, provided only such practice is carried on under the general supervision of a professional engineer, registered in this State.
>
> *Section 20. Exemptions.* The following persons shall be exempt from the provisions of this Act, to wit:
>
> (*c*) An employee or a subordinate of a person holding a certificate of registration under this Act or of any firm, co-partnership, corporation, or joint-stock association, authorized to practice professional engineering in accordance with the provisions of Section 17 hereof, or an employee of a person exempted from registration by classes (*a*) and (*b*) of this Section.

As to state practice in exemption: The analysis of 26 states made by Western Society of Engineers indicates that the laws as enacted in all except 6 specifically permit corporations, etc., to engage in the practice of professional engineering, provided those in responsible charge of the work are registered.

21 States exempt employees of registered engineers, 13 unqualifiedly, and 8 including the qualification that the work does not involve responsible charge. One which does not so exempt does exempt engineers employed by railroads or other interstate corporations whose employment is confined to such corporation. Other exemptions run to employees of public service corporations in varying terms.

Engineers Should Evolve the Standards

The "model law" provides for the setting up of standards by the states. Will not the dignity and standing of the profession be enhanced if it evolves for itself the standards which qualify for the title of "engineer"? Would not there be more assurance of appropriate standards and of their maintenance and uniformity than through legislative enactment? It is true that states may not delegate their powers unduly, but would not such a self-evolved standard lead in the fixing of state standards? Should not the profession actively forward the establishment of such a standard?

A procedure under contemplation by the E.C.P.D. would seem to provide a basis for such self-determination. Briefly it proposes:

1. The preparation by agreed methods of a list of approved engineering schools (the legislation demands such a list) and a uniform procedure in the granting of degrees.
2. Certification into the profession of engineering (carrying the right to use the title of engineer and to corporate membership in engineering societies) only after a period of practical experience and the establishment of qualification by examination or the equivalent.
3. Qualification standards to be at least equivalent and probably exceeding those established by legislation.

There is warrant for these changes in the legislation. The admitted animating purpose is the protection of the public against incompetency and fraud. A "certified" member of the profession in private employment could not be held incompetent if the standards on which his certification is based equaled or exceeded those of the legislation. His motive and opportunity for public fraud would be nil unless he likewise initiated a public relation and he would then be liable under the law.

It is believed that an embodiment of the suggestions herein made would be a step toward what must be the considered desire of the profession. It would afford the public the needed protection. It would put the profession in the desired dignified position before the public of initiating its standards of and by itself instead of having them imposed by law. It would substitute self determination for forced regimentation. It would make for uniformity of requirement. It would largely remove licensing from the field of political considerations. It would enormously simplify the process of enforcement. It would reduce the cost.

Very truly yours,

Arthur W. Berresford (A'94, M'06, F'14, member for life, and past-president)
418 Central Park West,
New York, N. Y.

Improving Section Meetings

To the Editor:

I suppose many Section chairmen face the same problem that I did while chairman of the Institute's Boston, Mass., Section in the matter of papers for their meetings. There seems to be a strong feeling in the Sections that they should have papers prepared especially for them by engineers of more or less authority on the subject selected and be presented in person before their meetings. I think this is entirely unnecessary and unwise.

It is quite a job for the Section officers to plan such a series of meetings during the Summer or early Fall carrying through their term of office. The individuals who are selected to be the authors are oftentimes busy on other things which seem to them more worth-while, and many times do not care to devote the time to prepare a special paper for the local group. I have found instances where an individual has been brought some 200 or 300 miles to present such a paper, and after having spent considerable time to prepare it (and probably he has prepared a very good paper) he then has the pleasure of presenting it before a small meeting, likely in many cases to be of the order of 30 to 50 individuals. It quite often happens that a good many of those present know very little about the subject, going to the meeting largely to meet their friends or perhaps with the thought of learning something about a subject in which they have only some passing interest.

I believe the value of any paper which is presented is, to a great extent, dependent on the discussion which that paper brings forth. At a meeting such as above mentioned there is apt to be very little discussion. Then, after the meeting has closed, the author is thanked by the Section officers and goes on his way and his paper received no further attention. This is too much of a burden all around. It is unnecessary and should be largely eliminated.

There are many valuable papers presented before the Institute's national conventions and District meetings, and while they receive much attention at these meetings, they can also receive, very profitably, consideration from many of the Sections at a later date. It should be no reflection on anybody to have such a paper presented at one or more Section meetings and thoroughly discussed by those present. It should not even be considered necessary for the author to present his paper in person, as that can readily be done by a local engineer who is familiar with the subject, and who very likely heard the original presentation and discussion. Such a procedure not only eliminates expense and trouble, but enables the individual member of a Section who was not able to attend the convention or District meeting to get much more out of the paper then he could by simply reading it and the discussion in Electrical Engineering or the Transactions. It is quite possible that it would bring forth additional valuable discussion which could be incorporated in the Institute's publications as a part of the discussion of that paper. This would also be helpful to the paper where time limitation prevented full discussion at the original presentation. I know that such a procedure is followed by some of the engineering societies in Great Britain and I have been surprised to read some of the discussions that a good paper brings forth in a local meeting.

I believe such a procedure would make the papers presented before the Institute of much more value to the local men and would make the meetings of local Sections more interesting and valuable to those present. As I said before, it would eliminate expense and nuisance, and here I mean the nuisance of more or less sand-bagging a busy man to prepare a paper when he does not feel the urge and when he knows that after being presented before a small group of people it will be buried and forgotten.

The technical program committee probably receives some papers that fail to meet requirements for a regular meeting of the Institute, yet at the same time have merit. Why not accept them for a Section meeting and so advise the Sections? Probably several sections would be glad to use such papers and the work of the authors would not be wasted.

These schemes seem to have considerable merit and should make the work of the Institute more valuable to the local member. I would like to see it tried out before some of our prominent Sections.

Very truly yours,

I. E. Moultrop (A'10, F'29)
Boston, Mass.

Characteristics of a Group of Engineers

To the Editor:

There is food for thought in the article by Thomas Spooner in the December 1935 issue of Electrical Engineering, pages 1571–6, in which he compares ratings of various qualities given to a group of engineers released during the depression from their first jobs with those given a group of their fellow workers who were retained.

There is some danger, however, of drawing incorrect conclusions from the table of "Faults and Weaknesses of Men Released" as engineers, unless the percentages deficient in each quality are compared directly with percentages deficient in the same qualities among men retained. For example, we find a very high percentage of men released rated as deficient in aggressiveness, and might conclude that aggressiveness is a requirement for engineering success, until we observe that almost as many retained engineers were rated as lacking in this quality. Aggressiveness cannot, therefore, apparently be regarded as a determining factor in engineering success in the company from which the data are taken.

The accompanying figure 1 shows graphically the comparison between the percentages of released and retained engineers for each of the qualities, as read from the charts presented by Mr. Spooner.

The graph indicates that the possession of an unimpressive personality, lack of ability to sell oneself, lack of initiative, and failure to improve oneself technically, which were characteristics of large percentages (26–45) of released employees, were found in a much smaller percentage of retained employees, and may therefore be regarded as factors determining retention.

In addition, ingenuity and analytical ability gain importance when viewed as means of differentiating between the 2 groups, for although the percentages of released employees rated as lacking in these traits are only 20 and 22, respectively, the percentage of retained employees rated in the same way is only 3 per cent in each case.

Diffidence, lack of aggressiveness, and insufficient evidence of ambition, which were named as faults of rather large percentages

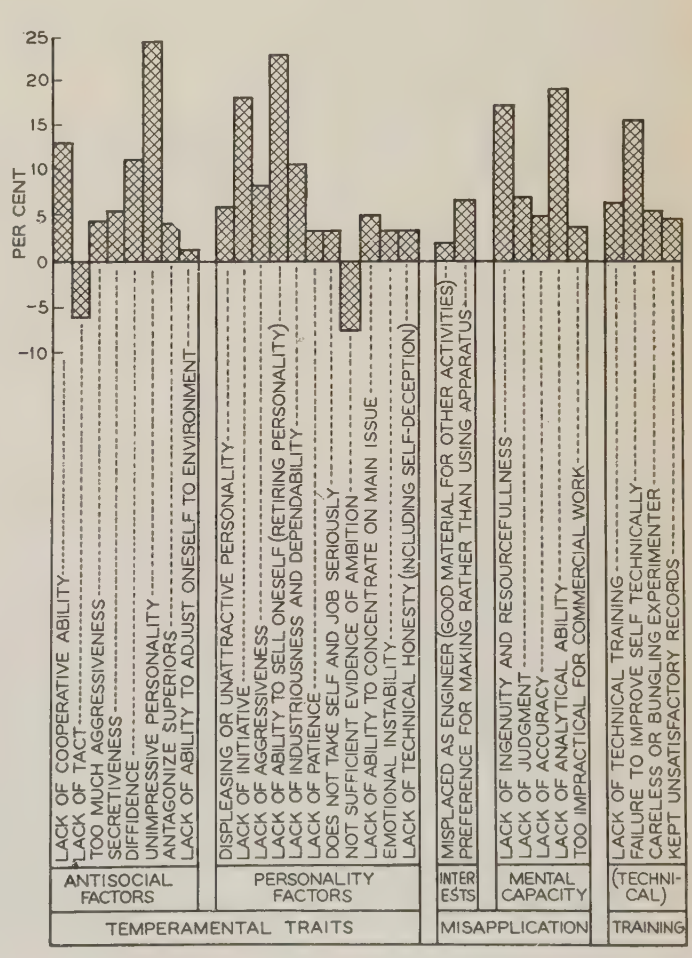


Fig. 1. Comparison of faults and weaknesses of men released and men retained

The percentages refer to the difference between the percentage of engineers deficient in the particular quality among those released and the corresponding percentage among those retained

Positive figures indicate a larger percentage in the released group; negative figures, a larger percentage in the retained group

of men released, are seen to be relatively unimportant as factors in retention, since these traits are found in percentages almost, if not quite, as large among retained engineers.

Lack of tact is actually a weakness of a larger percentage of the retained engineers than of those released.

The absolute significance of the difference in percentages depends on the number of cases in each group and these numbers were not given in the original article. But this graph indicating the relative importance of various qualities in differentiating between these groups may be of interest to those who read Mr. Spooner's illuminating article.

Very truly yours,

ELINOR G. HAYES
Hawthorne Works, Western Electric Company,
Chicago, Ill.

Electron Tubes for Resistance Welding

To the Editor:

In the January 1935 issue of ELECTRICAL ENGINEERING on page 90 appears a circuit diagram, figure 14, of an electron tube control for resistance welding (part of a paper "Application of Electron Tubes in Industry," by D. E. Chambers, pages 82–92). The author gives a good explanation of the theory of operation of the circuit. However, the action as he explains it, does not apply to the connections as shown in figure 14 of his paper.

I have found that if the grid and cathode connections of tube $T4$ are interchanged, that his explanation applies perfectly. Evidently these 2 connections into the timing circuit were inadvertently reversed when the diagram was drawn up.

Very truly yours,

W. M. BAUER (A'29)
Instructor in Elec. Engg.,
Northwestern University,
Evanston, Ill.

(EDITOR'S NOTE: Information received from the author indicates that the above correction can be made by reversing the 2 leads which connect the section labelled "timing circuit" with the section labelled "control circuit.")

Capacitor Motor With Double Cage Rotor

To the Editor:

It frequently happens that a capacitor motor is required to give a high starting torque, and a low slip when running at rated load. These requirements are antagonistic when a simple squirrel cage rotor is used, because a high starting torque calls for a high rotor resistance, whereas a low slip calls for a low rotor resistance.

The double squirrel cage rotor, when properly designed, is able to meet both of these requirements in the case of polyphase motors, where it has been used for some 30 or 40 years. So far as known the arrangement has not been used in capacitor motors. However, it seems possible that it should be useful for this purpose. It may even be that such rotors will save enough condenser capacity to cover their greater cost.

In 1929 W. J. Morrill ("The Revolving Field Theory of the Capacitor Motor," A.I.E.E. TRANSACTIONS, volume 48, April 1929, page 614) gave a method for calculating the performance of the ordinary capacitor motor. If the double cage is used, the same process will apply when Morrill's R_f and X_f are figured with the following values of R_2 and X_2,

$$R_2 = \frac{r''[r'^2 + (\delta x')^2] + r'[r''^2 + (\delta x'')^2]}{(r' + r'')^2 + \delta^2 (x' + x'')^2}$$

$$\cong \frac{r''[r'^2 + (\delta x')^2] + r'r''}{(r' + r'')^2 + \delta^2 x'^2}$$

$$X_2 = \frac{x''r'^2 + x'r''^2 + \delta^2 x'x''(x' + x'')}{(r' + r'')^2 + \delta^2(x' + x'')^2}$$

$$\cong \frac{x'r''^2}{(r' + r'')^2 + \delta^2 x'^2}$$

using $\delta' = S$ = slip of forward field; for the backward field, Morrill's R_δ and X_δ are figured from these same expressions for R_2 and X_2, except that $\delta = 2 - S$ is used. This simply means that in the single cage the rotor resistance R_2 and rotor leakage reactance X_2, both in stator terms, are "constants," while in the double cage they are functions of the slip and so each have different values in the 2 directions and different values at different slips.

In the above equations:

δ = slip in the polyphase motor formulas.
S = slip in the capacitor motor.

These equations are obtained from the equivalent network of the polyphase induction motor. The justification for using them here is that the gap flux in the condenser motor may be regarded as the resultant of 2 revolving fields which move in opposite directions. Each of these fields is physically identical with the revolving field in the polyphase machine. For this reason, the polyphase formulas must apply.

In the book "Modern Polyphase Induction Motors," translated from the German of F. Punga and O. Raydt by H. M. Hobart, will be found not only the derivation of these formulas, but rules for selecting the rotor proportions necessary to obtain a prescribed shape of speed-torque curve are given also. It seems possible that these rules will apply with fair accuracy also to the capacitor motor, or that they can be modified to fit. The symbols are:

r' = resistance of inner cage referred to primary main winding.
r'' = resistance of outer cage referred to primary main winding.
x' = leakage reactance of inner cage referred to primary main winding, counting only that part of the leakage flux which links with the inner cage alone.
x'' = leakage reactance of outer cage referred to primary main winding, counting only that part of the leakage flux which links with the outer cage alone. This is usually a small quantity and frequently is neglected.

That part of the rotor leakage flux which is common to both cages, such as rotor zigzag, and rotor tooth tip, is referred to the stator main winding and considered as part of the primary leakage reactance.

Very truly yours,

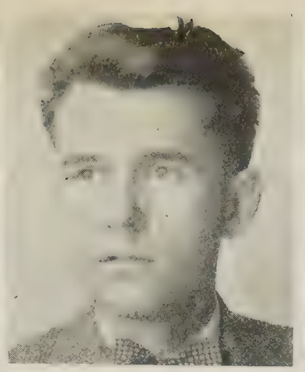
A. F. PUCHSTEIN (A'20, M'27)
Robbins & Myers, Inc.,
Springfield, Ohio

Personal Items

J. V. B. DUER (A'15, F'29) electrical engineer of the Pennsylvania Railroad, Philadelphia, Pa., has been appointed to the position of chief electrical engineer of the company. Mr. Duer was born at Poultney, Vt., in 1882, and graduated from Stevens Institute of Technology in 1903, with the degree of mechanical engineer. Upon graduation he became an electrical apprentice for the General Electric Company, spending one year at Lynn, Mass., and 2 years at Schenectady, N. Y. From 1906 until 1910, he was with the Long Island Railroad as wireman, electrical inspector, and chief clerk to the train master of electrified lines. In 1910, he was transferred to the Pennsylvania Railroad and for the following 3 years, while electric operation was being inaugurated into Pennsylvania Station, New York City, was foreman of motormen at New York, having responsible charge, qualifying, supervision, and discipline of men operating electric locomotives and trains, as well as supervision of the electric locomotives. From 1913 to 1919, he was assistant electrical engineer in charge of electrical work east of Pittsburgh and Erie, Pa., for the Pennsylvania Railroad, and was promoted to electrical engineer of that division in 1919. In 1920 his duties were extended to cover the entire system of the Pennsylvania Railroad, and he held this position until his recent promotion. In the recent project of electrifying between New York, Philadelphia, Baltimore, and Washington, Mr. Duer supervised not only the roadway construction, but also the designing and production of the new streamlined electric locomotives. Mr. Duer has served the Institute as a

J. V. B. DUER

A. A. KRONEBERG



F. C. LINDVALL

M. M. ROCKWELL

member of its committee on transportation for many years, having been chairman 1926–28. He has presented articles on electric traction before the Institute and other organizations. In 1922, he was a delegate to the International Railway Congress in Italy, and in 1930 was reporter for America to the International Congress on Electric Locomotives for Main Line Traction. He is chairman of the electrical section of the Association of American Railroads, and a member of the St. Nicholas Society of New York.

Mabel Macferran Rockwell (A'28, M'35) assistant engineer, Metropolitan Water District of Southern California, has, with her co-author, A. A. Kroneberg (A'28, M'34) been awarded the 1934 A.I.E.E. Pacific District prize for best paper, for their paper "Power Limits of 220 Kv Transmission Lines." Mrs. Rockwell was born in Philadelphia, Pa., in 1902. She was educated at Bryn Mawr College, and became interested in engineering through science courses there and summer jobs with Leeds and Northrup Company. She obtained her degree of bachelor of science in mathematics from Massachusets Institute of Technology in 1925. After one year, 1925–26, as Elwell fellow at Stanford University, Calif., working with the late Prof. Harris J. Ryan (A'87, M'95, F'23, and past-president) in the million volt laboratory, she received the degree of electrical engineer from that institution in 1926. She then entered the testing department of the Southern California Edison Company, Ltd., being engaged until 1928 on transformer testing, research, and development work; with others she obtained patent for the "Serjdetour" telephone protector. From 1928 until 1931 she was technical assistant to the operating engineer of the Southern California Edison Company, specializing in studies of high voltage power transmission and system stability. During this period she helped to work out the economic design of the company's proposed Boulder Dam transmission line, upon which the prize winning paper was based. Since 1931 she has been assistant engineer of the Metropolitan Water District of Southern California, at Los Angeles, being engaged in analysis of electrical problems connected with the Colorado River Aqueduct. These have included economic and engineering studies for the construction power system and the main transmission system. She also has done considerable work on the Colorado River power development problem. Mrs. Rockwell has presented 2 previous Institute papers, one of which "Parallel Operation of Transformers" received the 1929 initial paper prize for the Pacific District. As announced in Electrical Engineering for July 1935, page 787, Mrs. Rockwell and another Institute member, E. W. Rockwell (A'21, M'35) were married on June 7, 1935. She is a member of Sigma Xi.

R. W. Sorensen (A'07, M'13, F'19, and past vice president) senior professor of electrical engineering at California Institute of Technology, Pasadena, was honored at a special meeting held at Pasadena in June 1935, and attended by 120 engineers, scientists, educators, and city officials. A hand-illuminated parchment testimonial was among the gifts bestowed upon him, and a scroll was presented him by officers of the Institute's Los Angeles Section. The occasion marked 25 years of service given by Professor Sorensen to California Institute of Technology. Professor Sorensen, born at Alta Vista, Kan., in 1882, was educated at the University of Colorado at Boulder. Entering the test department of the General Electric Company at Schenectady, N. Y., in 1905, he became foreman of the test department the following year, a few months later entering the commercial section of the transformer engineering department of the company. In 1910, he became associate professor of electrical engineering at California Institute of Technology (then Throop Polytechnic Institute). He was made full professor in 1911 and has held that position continuously since then. In addition to his educational work, he has engaged in a consulting practice, and is very active in local affairs. He has served the Institute on many of its committees and other activities, and has presented several Institute papers.

A. A. Kroneberg (A'26, M'34) technical assistant to operating engineer, Southern California Edison Company, Ltd., Los Angeles, has, with his co-author, Mrs. Mabel Macferran Rockwell (A'28, M'35) been awarded the 1934 A.I.E.E. Pacific District prize for best paper for their paper entitled "Power Limits of 220 Kv Transmission Lines." Mr. Kroneberg was born in Ekaterinbourg, Russia, in 1899, and after being educated at schools in Russia came to the United States in 1923, when he entered the electrical engineering course of California Institute of Technology. Following graduation in 1926, he entered the training course of the Southern California Edison Company, Ltd., and became electrician at the Long Beach steam station. Mr. Kroneberg was appointed to his present position in 1931. He is a member of Tau Beta Pi.

W. E. Wickenden (A'07, M'13) president of Case School of Applied Science, Cleveland, Ohio, has been awarded the 8th Lamme Medal of the Society for the Promotion of Engineering Education, which was presented to him at the 43d annual meeting of that society at Atlanta, Ga., June 26, 1935. Mr. Wickenden was born at Toledo, Ohio, in 1882. After graduating from Denison University, Granville, Ohio, with the degree of bachelor of science in 1904, he took graduate work in electrical engineering at the University of Wisconsin, Madison for 2 years. After serving as an instructor at Rochester (N. Y.) Mechanics Institute, and at the University of Wisconsin, for a few years, he was, between 1909 and 1916, assistant professor of electrical engineering in Massachusetts Institute of Technology, Cambridge, becoming associate professor in the latter year. In 1917, he became supervisor of educational work for the engineering department of the Western Electric Company, New York, and the next year, manager of the company's personnel department. He later became chairman of the company's personnel committee. Doctor Wickenden joined the American Telephone and Telegraph Company, New York, N. Y., in 1921, as assistant vice president in charge of the recruiting and development of supervisory and technical personnel for the Bell system. Between 1923 and 1929, he was director of investigation for the Society for the Promotion of Engineering Education, and since 1929 has been president of Case School of Applied Science. Doctor Wickenden was president of the S.P.E.E. during 1933–34. He has presented many papers and addresses before the Institute and other societies, and is the author of "Illumination and Photometry." He is a member of several other societies, and has received a number of honorary degrees.

F.C. Lindvall (A'26) assistant professor of electrical engineering, California Institute of Technology, Pasadena, has been awarded the 1934 A.I.E.E. Pacific District prize for initial paper for his paper "A Low Discharge Anemometer." Professor Lindvall was born at Moline, Ill., in 1903. He was educated at the University of California and the University of Illinois, receiving the degree of bachelor of science from the latter institution in 1924. During 1924–25 he was with the Los Angeles (Calif.) Railway Corporation in electrolysis work. During 1925–28 he was teaching fellow at the California Institute of Technology, receiving the degree of doctor of philosophy in electrical engineering and physics in 1928. For the following 2 years he was in the engineering general department of the General Electric Company, Schenectady, N. Y. He has been assistant professor of electrical engineering at California Institute of Technology since 1930.

D. C. Jackson, Jr. (A'23, M'26, F'30) who has been head of the department of electrical engineering of the University of Kansas, Lawrence, is now director of Lewis Institute, Chicago, Ill. He will, however, devote some time to electrical engineering at the University of Kansas until February 1936. Professor Jackson was born at Madison, Wis., and after receiving the degree of bachelor of arts at Harvard University served in the U.S. Army as a coast artillery officer. He then entered the co-operative engineering course at Massachusetts Institute of Technology, where he received the degrees of bachelor of science and master of science in 1921 and 1922, respectively. In the latter year he went to the University of Missouri, Columbia, as an instructor in the department of electrical engineering, and 2 years later was appointed assistant professor in charge of electrical engineering at Trinity College, Duke University, Durham, N. C. In 1925 Professor Jackson went to Louisville, Ky., as professor of electrical engineering and head of the combined departments of mechanical and electrical engineering at the Speed Scientific School, University of Louisville, and since 1930 he has been at the University of Kansas. Professor Jackson is a member of the Institute's committee on education and the committee on power transmission and distribution, and has served as chairman of the Louisville Section and as a Branch counselor. He is also a member of The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education, and has presented a number of papers.

D. R. Tibbetts (A'35) in charge of design and operations, San Francisco-Oakland Bay Bridge Construction Radiotelephone System, San Francisco, Calif., has been awarded the 1934 A.I.E.E. Pacific District prize for Branch paper for his paper "San Francisco-Oakland Bay Bridge Construction Radiotelephone System." Mr. Tibbetts was born at Berkeley, Calif., in 1911. During summer vacations he did work on hydroelectric development for the Pacific Gas and Electric Company, in 1929, and for the dial central office installation of The Pacific Telephone and Telegraph Company; also installation of independent telephone and signal system, 1931 and 1932. He graduated from the University of California, Berkeley, in 1934, with the degree of bachelor of science in electrical engineering. During 1934 and 1935 he did consulting communications work for the American bridge division of the United States Steel Corporation, the department of public works of the state of California, and the East Bay Municipal Utility District. At present, and since 1933, he has held his present position.

D. C. Jackson (A'87, M'90, F'12, past-president and member for life) has accepted the invitation of the Institute of Electrical Engineers of Japan to deliver the Iwadare lectures on electrical engineering topics this year. Professor Jackson will leave Cambridge in September, arriving in Japan in October. As part of the Iwadare Foundation a series of lectures is given from time to time by noted American electrical engineers, for the purpose of bringing to Japan American advances and practices in the electrical art. In connection with Professor Jackson's retirement in June 1935 as head of the department of electrical engineering of Massachusetts Institute of Technology, Cambridge, after 28 years of service in that position, a brief biographical sketch appeared in Electrical Engineering for May 1935, pages 574–5. He recently was nominated by the Engineers' Council for Professional Development to be a member of the delegatory committee for the accrediting of engineering schools in region No. 1, and has been appointed to that committee.

R. H. Dearborn (A'07, M'14, F'30) head of the department of electrical engineering and since 1933 acting dean of the school of engineering and industrial arts at Oregon State College, Corvallis, has been appointed dean. He was born at Salem, Ore., and received the degree of bachelor of arts at Willamette University and of electrical engineer at Cornell University. Following graduation from the latter in 1900 he was employed by the Portland General Electric Company until he became professor of electrical engineering at the University of Oregon in 1902, establishing the department. Dean Dearborn was head of this department from 1904 to 1914, when he became head of the department of electrical engineering at Oregon State College with the combining of all the electrical engineering courses of the state at this college. He held this position since that time, and in addition during 1913–15 was electrical engineer for the Public Service Commission of Oregon. He occasionally has written technical articles.

C. B. Aiken (M'35) member of the technical staff of Bell Telephone Laboratories, Inc., New York, N. Y., who since the death of J. H. Morecroft (A'06, M'12, F'19) in 1934 has been teaching his courses in electronics at Columbia University, has been appointed associate professor of electrical engineering in charge of the department of communication engineering at Purdue University, Lafayette, Ind. Doctor Aiken received the degree of bachelor of science from Tulane University, and from Harvard University the degrees of master of science in electrical communication engineering, master of arts, and doctor of philosophy. Following experience in geophysical exploration work, he became a member of radio apparatus development department of Bell Telephone Laboratories, Inc., in 1928, and 2 years later was made supervisor in charge of broadcast receiver design. Doctor Aiken, a member of the Institute of Radio Engineers, is the author of a number of papers on radio broadcasting.

J. G. Barry (A'03) senior vice president of the General Electric Company, Schenectady, N. Y., was recently elected to an honorary vice presidency and has retired, although he will be available for consultation. Mr. Barry has been with the General Electric Company and its predecessor, the Thomson-Houston Electric Company, since 1890, going to Schenectady in 1894 as a member of the railway department. Later he became assistant manager of the department, and in 1907 was appointed manager. In 1917 the duties of general sales manager were added, and in 1922 he was appointed a vice president, serving as active head of the apparatus sales organization. Mr. Barry was for many years a member of the executive committee of the American Electric Railway Association.

K. M. Klein (A'35) electrical engineer, Oregon State Highway Commission, has, with his co-author E. J. Harrington, been awarded the 1934 A.I.E.E. North West District prize, for their paper "The Influence of Ground Plane Proximity Upon the Polarity of Sphere-Gap Spark-Over." Mr. Klein was born at Portland, Ore., in 1912, and graduated from Oregon State College in 1934 with the degree of bachelor of science in electrical engineering, having majored in power work. During the summer of 1931, he assisted in electrical testing on the Rogue River Bridge in Oregon, and since graduation has been in the employ of the Oregon State Highway Commission as electrical engineer. Most of his work has been with the bridge department in connection with movable span bridges. While a student at Oregon State College, he was secretary of the Student Branch of the A.I.E.E. He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Tau.

O. H. Caldwell (A'13, M'22) formerly federal radio commissioner, and more recently editor of *Radio Retailing* and *electronics*, both published by the McGraw-Hill company, has become editor of *Radio Today*, a new magazine which is being brought out by Caldwell-Clements, Inc., New York, N. Y. Doctor Caldwell has served the New York Electrical Society as president 1932–34, and is a director of the Institute of Radio Engineers, and trustee of the New York Museum of Science and Industry. He is a member of radio committees of several organizations, and has become well known for his broadcasts over nationwide networks, in his effort to bring better radio reception to American homes. Joining the McGraw-Hill company as associate editor of the *Electrical World* in 1910, he edited *Electrical Merchandising* 1916–27, *Radio Retailing* 1925–35, and *electronics* 1930–35.

R. W. Warner (M'28) professor of electrical engineering, University of Kansas, Lawrence, has been appointed exchange professor at Massachusetts Institute of Technology for one year. Professor Warner is a graduate of Washburn College, Topeka, Kan., and of the University of Kansas. He was an instructor in electrical engineering at the latter and at the University of Wisconsin during the period 1921 to 1923, after which he was connected with the General Electric Company and the Kansas City Power and Light Company. He returned to the University of Kansas in 1928 as assistant professor, and the following year became associate professor. Professor Warner is also a member of the Society for the Promotion of Engineering Education.

E. S. Byng (M'20, F'29) vice chairman and joint managing director of Standard Telephones and Cables Limited, London, England, has been awarded a prize for his paper "The Engineer Administrator" presented before the Institution of Electrical Engineers (Great Britain) during the past session. Mr. Byng is also the author of an Institution paper "Telephone Line Work in the United States" given in 1920, for which he was given the Fahie premium. This paper followed a visit to America to study the practices of the American Telephone and Telegraph Company and promoted great discussion throughout Great Britain. Mr. Byng has been elected as a member of the council of the Institution of Electrical Engineers (Great Britain) and takes office in October 1935.

R. H. Frazier (A'25, M'32) assistant professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been appointed exchange professor at the University of Kansas Lawrence, for one year. Professor Frazier received the degree of bachelor of science at Massachusetts Institute of Technology in 1923, and the degree of master of science in 1932, and was an instructor in electrical engineering from 1925 to 1931, when he was appointed assistant professor. He is the author of several papers on educational and scientific topics.

Vannevar Bush (A'15, M'19, F'24) vice president and dean of engineering, Massachusetts Institute of Technology, Cambridge, has been nominated for appointment as an additional representative of the Institute upon the division of engineering and industrial research of the National Research Council. Dean Bush has been a member of several Institute committees.

Joseph Hellenthal (A'14, M'23) electrical engineer, Puget Sound Power and Light Company, Seattle, Wash., has been elected chairman of the engineering section of the Northwest Electric Light and Power Association. Mr. Hellenthal is a member of the Institute's committees on automatic stations, protective devices, and membership.

K. C. Roy (A'31) is now sales manager of The Bengal Electric Lamp Works, Ltd., Calcutta, India. Mr. Roy organized the pioneer lamp manufacturing company in India, and is a director of Electro-Chemical Industries, Ltd., and Pioneer Glass Works, Ltd.

E. W. Allen (A'03, F'22) vice president, General Electric Company, Schenectady, N. Y., has been appointed a member of the apparatus sales committee and given supervision of the contract service department of the company.

H. A. Wagner (A'98, M'03, and member for life) president, Consolidated Gas, Electric Light and Power Company of Baltimore, Md., has been elected a trustee of Stevens Institute of Technology, Hoboken, N. J.

R. V. Sprague (A'08) former electrical engineer and superintendent for D. P. Robinson and Company of Argentina, Buenos Aires, is now general electrical foreman with the U.S. Bureau of Reclamation, Boulder City, Nev.

W. S. Potter-Hanwell (A'34) former chief electrical engineer in the irrigation department of the Egyptian government at Khartoun, Sudan, has engaged in practice as a consulting engineer at London, England.

C. C. Crane (A'25, M'31) former engineer for the Northern Indiana Public Service Company, Hammond, is now electrical engineer in the bridge division of the Michigan State Highway Department, Lansing.

I. C. Blickenstaff (A'34) former plant extensions engineer, The Chesapeake and Potomac Telephone Company of Virginia, Richmond, is now staff engineer for The Chesapeake and Potomac Telephone Companies, Washington, D. C.

E. O. Shreve (A'06) vice president, General Electric Company, Schenectady, N. Y., has been appointed chairman of the apparatus sales committee, which will direct the general commercial policies of the apparatus departments of the company.

A. K. Jones (A'16 and Life Member) formerly vice president and general manager, Cia. Cubana de Electricidad, Inc., Havana, Cuba, is now connected with Cia. Chilena de Electricidad, Ltd., Santiago, Chile.

J. P. Percy (A'26) former assistant superintending engineer for the Southern Sugar Company, Clewiston, Fla., has accepted the position of chief engineer with the Aguirre Sugar Company, Inc., Central Aguirre, Puerto Rico.

Ray Raneri (A'34) electrical engineer with the Public Works Administration, U.S. Department of Interior, who has been at Washington, D. C., is now at New York, N. Y.

M. O. Troy (A'08, M'12) manager of the central station department, General Electric Company, Schenectady, N. Y., has been given supervision of central station commercial engineering.

D. H. Lewis (A'25, M'32) general manager, St. Louis County division, Union Electric Light and Power Company, Webster Groves, Mo., has been elected vice president in charge of suburban operations.

L. E. Dickinson (A'08) general manager, Mississippi River Power Company, Keokuk, Iowa, has been named vice president of the company and other affiliate companies.

H. J. Annen (A'34) is now an electrician with the Gulf Refining Company at Port Arthur, Texas.

B. J. McNellis (A'34) formerly with the International Telephone and Telegraph Company, New York, N. Y., is now with the General Electric Company at Bridgeport, Conn.

E. W. Middleton (M'31) who has been local manager for the Cia. de Electricidad del Sud Argentina at Junin, is now operating manager for the company at Buenos Aires.

H. H. Darling (A'32) who has been an electrical contractor at Smithers, B. C., Can., is now service manager for Electrical Maintenance and Repairs Company, Ltd., Toronto, Ont.

D. C. Kennedy, Jr. (A'33) formerly with the Appalachian Electric Power Company, Roanoke, Va., is now in the test department of the General Electric Company at Schenectady, N. Y.

A. N. Stanton (A'29) formerly with the T.C.U. Radio Laboratories, Fort Worth, Texas, is now vice president and chief geophysicist of Geophysical Petroleum Surveys, Inc., Dallas.

E. O. Martinson (A'33) is now a junior engineer with the Mason-Walsh-Atkinson-Kier Company at Mason City, Wash., in connection with the construction of Grand Coulee Dam.

P. N. Vassil (A'35) is now assistant cartographic engineer with the U.S. Coast and Geodetic Survey, Department of Commerce, Washington, D. C.

P. F. Williams (A'07) former assistant electrical engineer, Commonwealth Edison Company, Chicago, Ill., is now with G & W Electrical Specialty Company, Chicago.

A. L. Henry (A'31) of Perry, N. Y., is now junior engineer with the Sprague Specialties Company at North Adams, Mass.

F. J. Boehm (M'25) vice president of the Union Electric Light and Power Company, St. Louis, Mo., for the past 15 years, has been made executive vice president.

A. F. Puchstein (A'20, M'27) development engineer, Robbins and Myers, Inc., Springfield, Ohio, has been appointed chief engineer.

Ernest Lienhard (A'31) former electrical engineer with Elmac, Inc., Manila, P. I., is now connected with Red V Cocoanut Products, Ltd., Lucena, Tayabas, P. I.

R. M. Garrison (A'33) former engineer with J. H. McEvoy and Company, Houston, Texas, is now connected with the Mission Manufacturing Company at Houston.

L. A. De Beer (A'30) until recently engineer, Cablerie de Dour, Dour, Belgium, is now chief of works at the Mons School of Mines, Mons, Belgium.

R. T. Ward (A'30) former engineer with the International General Electric Company, Schenectady, N. Y., is now in London, England, where he is a sales engineer for Aluminium Union Limited.

Obituary

Benjamin Stalker Read (M'23) president of the Southern Bell Telephone and Telegraph Company, Atlanta, Ga., died July 23, 1935. He was born at Carthage, Tenn., January 21, 1876. In 1890, he entered the service of the Cumberland Telephone and Telegraph Company, at Carthage, Tenn., as messenger boy and local agent. In 1903, he became manager of this company at Owensboro, Ky., and in 1904, manager at Chattanooga, Tenn. In 1904, he became district manager for the company with headquarters at Louisville, Ky., and in this and all of the positions which he subsequently held, his responsibilities included the supervision not only of engineering, but of construction, maintenance, and operation of the telephone plant. From 1908 until 1912, he was district superintendent for the company for Louisiana and Mississippi, with headquarters at New Orleans. After a few months in 1912 as general manager of the Bell Telephone Company of Missouri, with headquarters at St. Louis, he became that year general manager of the Missouri and Kansas Telephone Company, with headquarters in Kansas City, Mo. From 1914 until 1919, he was vice president in charge of operation of the Southwestern Bell Telephone System (now the Southwestern Bell Telephone Company) operating in several western states with headquarters at St. Louis, Mo. During a portion of 1919, he also served as a member of the supervisory staff, Bell system, under United States Telephone and Telegraph Administration, with headquarters in New York City. From 1919 until 1924, he was president of The Mountain States Telephone and Telegraph Company, with headquarters at Denver, Colo., and from 1924 until his death he was president of the Southern Bell Telephone and Telegraph Company and the Cumberland Telephone and Telegraph Company with headquarters at Atlanta, Ga. Mr. Read was president of the Telephone Pioneers of America in 1925. During the World War he was a member of the War Camp Survey Committee. He was a director of the Fourth National Bank of Atlanta, and a member of several clubs in that city.

William Henry Powell (A'08, M'10, F'12) engineer in charge of d-c design, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died July 8, 1935. Mr. Powell was born in England, September 14, 1867, and came to America at 3 years of age. He attended Cornell University at Ithaca, N. Y., where he was graduated in 1890 from the mechanical engineering course. He received the degree of master of mechanical engineering from Cornell University in 1901. During 1890–91, he was in the laboratory of the Westinghouse Electric and Manufacturing Company, entering the railway department of the Edison General Electric Company in 1891. During 1892–93, he was electrical draftsman for the Mather Electric Company, Manchester, Conn.; during 1894–95, instructor in electrical engineering at Lehigh University; during 1895–96, superintendent of the Perkins Electric Lamp Company, Hartford, Conn.; during 1897–1900, chief engineer of the Keystone Electric Company, Erie, Pa.; during 1900–01 a fellow in electrical engineering at Cornell University; during 1901–02, again chief engineer of the Keystone Electric Company, and during 1902–04, engineer in charge of controllers for multivoltage systems for the Crocker-Wheeler Company, Ampere, N. J. In 1904, Mr. Powell went as electrical engineer in charge of d-c motors and controllers for the Bullock Electric Manufacturing Company, Cincinnati, Ohio, which had just become affiliated with the Allis-Chalmers company of Milwaukee. During 1907–08, he was general superintendent and works manager of the Bullock Company, moving to Milwaukee in 1908, when he became electrical engineer in charge of d-c apparatus, remaining in this position for some 27 years. Mr. Powell is perhaps best known as the inventor of the "frog-leg winding," which improved commutation in d-c machines. He was a member of the Milwaukee Engineers' Society and of Sigma Xi. Mr. Powell had served the Institute on its committees on electrochemistry and electrometallurgy 1920–22, industrial and domestic power 1915–16, and standards 1914–15; and had been chairman of the Milwaukee Section.

Lewis Fussell (A'06, M'22) professor of electrical engineering and chairman of the department of electrical engineering, Swarthmore College, Swarthmore, Pa., died July 15, 1935. He was born at Media, Pa., April 22, 1882. In 1902 he received the degree of bachelor of science in physics from Swarthmore College, and in 1903, that of master of science in electricity from Swarthmore. He studied at Cornell University in the summer of 1904, and after entering the University of Wisconsin in 1905, received the degrees of electrical engineer and of doctor of philosophy there in 1907. He had started teaching at Swarthmore College in 1903, being an instructor in physics until 1905. During 1906–07, he was an assistant in electrical engineering at the University of Wisconsin. Since 1907, he has been teaching in the electrical engineering department of Swarthmore College. About 1910, he became assistant professor, and in 1921 professor in charge of the department. Professor Fussell spent several summer vacations in electrical manufacturing and operating companies, and had done considerable consulting work, being known as a specialist in public utility engineering. He had served the Institute on its committees on education 1924–25, and production and application of light 1928–29, and as chairman of the Philadelphia Section. He was the author of "The Self-Excited Polyphase Asynchronous Generator," a technical handbook (1903) and several technical articles. He was a member of the Illuminating Engineering Society, Institute of Radio Engineers, the American Association for the Advancement of Science, and of Sigma Tau and Sigma Xi fraternities.

Frank Eugene Smith (A'94, M'99, and member for life) retired, San Francisco, Calif., died January 23, 1935, according to information recently received at Institute headquarters. Mr. Smith was born November 26, 1856, at Don Pedro, Calif. In 1876, he became lineman with the American District Telegraph Company, San José, Calif., and a year later was placed in charge of all electrical apparatus, which subsequently comprised not only the telegraph, but fire alarm and telephone systems. In 1880 he became lineman for the Pacific Bell Telephone Company, San Francisco, and several months later was made chief inspector of central offices. In 1883, he became chief engineer and electrician of the San José Light and Power Company, and in 1886, chief electrician of the then Edison Light and Power Company, San Francisco. Mr. Smith held this position for many years and was a pioneer in many electrical installations in California. He subsequently became a consulting and supervising electrical engineer, in San Francisco, and for some 30 years was in charge of the standardizing work and sales agent on the Pacific Coast for the Weston Electrical Instrument Company.

Membership

Recommended for Transfer

The board of examiners, at its meetings held May 29 and July 24, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dawes, C. L., assoc. prof. of E.E., Harvard Univ., Cambridge, Mass.
Penn, Marion, gen. mgr., elec. dept., Public Service Elec. and Gas Co., Newark, N. J.
Savant, Domenico P., prof. of E.E. and dean of engg., Georgia School of Tech., Atlanta, Ga.

3 to Grade of Fellow

To Grade of Member

Almquist, Carl T., assoc. prof. of E.E., Univ. of Oklahoma, Norman.
Bathe, C. E., supt. of standards and radio, Oklahoma Gas & Elec. Co., Oklahoma City.
Bedell, William B., telephone engg., Am. Tel. and Tel. Co., New York, N. Y.
Boyd, Spencer W., cons. engr., Newcomb & Boyd, Atlanta, Ga.
Capron, R. B., asst. distrib. engr., Utica Gas & Elec. Co., Utica, N. Y.
Carter, Leonard L., E.E., Anaconda Wire and Cable Co., Hastings-on-Hudson, N. Y.
Evans, M. F., elec. supt., Wright-Hargreaves Mines, Kirkland Lake, Ont., Can.
Farrar, W. B., E.E., Mississippi River Valley Div., U. S. Government Civil Service, St. Louis, Mo.
Heinrich, Walter A., vice president and chief engr., James R. Kearney Corp., St. Louis, Mo.
Holton, Theodore R., asst. E.E., Am. Steel and Wire Co., Worcester, Mass.
Howes, Douglas E., assoc. prof. of E.E., Norwich Univ., Northfield, Vt.
Kimberly, M. C., supervising line extension estimator, Commonwealth Edison Co., Chicago, Ill.
Lattimer, Irving E., engg. dept., Am. Tel. and Tel. Co., New York, N. Y.
Leerburger, F. J., senior asst. engr., Maurice R. Scharff, New York, N. Y.

Lindblom, R. E., assist. prof. of E.E., Univ. of Washington, Seattle.
McKim, James B., member of technical staff, Bell Tel. Labs., Inc., New York, N. Y.
Morris, E. W., control engr., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Price, Harold W., prof. of E.E., Univ. of Toronto, Toronto, Ont., Canada.
Purucker, R. E., engr., Public Service Commission, State Capital, Madison, Wis.
Roberts, J. M., asst. prof. of E.E., University of Louisville, Louisville, Ky.
Sabbagh, E. M., asst. prof of E.E., Purdue Univ., Lafayette, Ind.
Seaman, B. C., E.E., Elliott Co., Ridgway, Pa.
Seletzky, A. C., asst. prof. of E.E., Case School of Applied Science, Cleveland, O.
Starbird, Levi C., transmission and protection engr., Southwestern Bell Tel. Co., Dallas, Texas.
Warwick, George G., supt., Vancouver Pwr. Co., Lake Buntzen, Burrard Inlet, B. C., Canada.
Wensley, R. J., asst. general mgr., I-T-E Circuit Breaker Co., Philadelphia, Pa.

26 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Sept. 30, 1935, or Nov. 30, 1935, if the applicant resides outside of the United States or Canada.

Adam, L. G., (Member), Amer. Tel. & Tel. Co., New York, N. Y.
Baker, E. M., Bartlett Hayward Co., New York, N. Y.
Bausch, K. M., G. M. Simonson, San Francisco, Calif.
Chappell, G. C., Libbey-Owens-Ford Glass Co., Rossford, Ohio.
Chisholm, C. E., Bd. of Transportation, New York, N. Y.
Conwell, E. M., (Member), Albuquerque Gas & Elec. Co., Albuquerque, N. M.
Dunleavey, F. S., (Member), Magnavox Co., Ft. Wayne, Ind.
Gaalaas, G. L., Empire Sheet & Tin Plate Co., Mansfield, Ohio.
Ganz, A. G., Bell Tel. Lab. Inc., New York, N. Y.
Griffith, H. C. (Member), Pennsylvania Railroad, Philadelphia, Pa.
Higbee, E. W. Jr., (Member), Amer. Tel. & Tel. Co., New York, N. Y.
Koch, H. F. (Member), New England Pr. Engg. & Service Corp., Fall River, Mass.
Kofoid, M. J., 4416 N. E. 10th Ave., Portland, Ore.
Lindberg, H. C., General Elec. Co., New York, N. Y.
Lomont, C. F. (Member), Magnavox Co., Ft. Wayne, Ind.
Mathews, L. E., 239 Keystone Place, Reno, Nev.
Morehouse, S. B., Leeds & Northrup Co., Philadelphia, Pa.
Oler, C. B. (Member), Gibbs & Hill Inc., New York, N. Y.
Peterson, R. R. (Member), borough Eng., Manhattan office, E. R. B., New York, N. Y.
Polk, O. H., University of Arizona, Tucson.
Quinlan, J. W. (Member), Indianapolis Bell Tel. Co., Indianapolis, Ind.
Rothfus, E. A., Mason & Walsh Co., Fort Peck, Mont.
Sauberman, N. H., Ritter Hotels, Long Beach, N. Y.
Shoults, D. R., General Elec. Co., Schenectady, N. Y.
Swering, J. B., Hartford Steam Boiler Inspection & Insurance Co., Conn.
Thayer, N. B., Toledo Edison Co., Ohio.
Warren, H. S., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Wilkinson, R. I., Bell Tel. Lab. Inc., New York, N. Y.
Yeager, C. R., Hudson & Manhattan R. R. Co., New York, N. Y.

29 Domestic

Foreign

Basta, J. J., Kolben Co., Praha-Vysocany, Czechoslovakia
Canagarayar, R., Messrs. Laurence Scott & Electromotors Ltd., Norwich, England.
Kennedy-Potts, N. D., Port Elizabeth Tech. Col., Port Elizabeth, So. Africa.
Keshavan, V. K., Nagercoil Elec. Supply Corp., Nagercoil, So. India.
Peralta-Esquivel, A., Cia. Electrica de Limon, Port-Limon, Costa Rica, C. A.
Rao, B. I. Madhav, Sri Brahma Vidzambal Elec. Supply Corp. Ltd., Ramachandrapuram Post, via Tirumayam, So. India.
Scott-Taggart (Fellow), Harlow Laboratories, Frinton-on-Sea, England.
Thornton, N. (Member) Public Works Dept., Lahore, India.
Waliuddin, S., Fathullah Beg St., Hyderabad Dn., India.

9 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bock, F. S., 1642 W. Broad St., Richmond, Va.
Brune, Otto, 214 White St., Waverly, Mass.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Clark, S. W., Apartado 2887, Mexico, Mex.
Cole, Fred H., 1116 Washington Blvd., Oak Park, Ill.
Condon, E. J., Jr., Gen. Del., Phoenix, Ariz.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Martinoff, V. M., 2150 Queen St., Toronto, Ont., Can.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Rozelle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Schellberg, Kenneth O., 4115—51st St., S., Seattle, Wash.
Schlosser, Walter H., Dominion Elec. Power, Ltd., Regina, Sask., Can.
Sillstrop, John P., Eldorado Towers, 300 Central Park West, New York, N. Y.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.

19 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

ELEMENTS of ELECTRICITY. By A. Zeleny. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 526 p., illus., 8x5 in., cloth, $3.00. A comprehensive first course in electricity, including much practical information.

PHENOMENON of SUPERCONDUCTIVITY. Ed. by E. F. Burton. Toronto, Univ. of Toronto Press; Chicago, Univ. of Chicago Press, 1934. 112 p., illus., 9x6 in., cloth, $2.50. A simple but rather comprehensive statement of the methods of producing and measuring low temperatures and an outline of the main facts of superconductivity.

SYMPOSIUM on ILLUMINATION. Ed. by C. J. W. Grieveson, with a foreword by K. Edgcumbe. Lond., Chapman & Hall, 1935. 229 p., illus., 9x6 in., cloth, 13s 6d. Ten lectures given in 1933 at London, under the auspices of the National Illumination Committee and the Illuminating Engineering Society, discussing theoretical and practical problems.

AUTOBIOGRAPHY of JOHN HAYS HAMMOND. 2 vols. N. Y., Farrar & Rinehart, 1935. 813 p., illus., 9x6 in., cloth, $5.00. At the age of 80 this famous mining engineer writes the story of a life that has been full of adventure in 3 continents.

RESEARCH, the Pathfinder of Science and Industry. By T. A. Boyd. N. Y. and Lond., D. Appleton-Century Co., 1935. 319 p., 8x5 in., cloth, $2.50. Explanation of the purpose and methods of research for the business man and the young man who thinks of it as a possible vocation.

(A) SOURCE BOOK in PHYSICS. By W. F. Magie. N. Y. and Lond., McGraw-Hill Book Co., 1935. 620 p., illus., 9x6 in., cloth, $5.00. Extracts of most significant portions of important original papers contributing to physics during the period 1600–1900.

(The) BOOK of STAINLESS STEELS, Corrosion Resisting and Heat Resisting Chromium Alloys. Ed. by E. E. Thum. 2 ed. Cleveland, American Society for Metals, 1935. 787 p., illus., 9x6 in., cloth, $5.00. New, larger edition containing the experience of specialists in the manufacture and use of heat and corrosion resisting steels.

CONTRACTS in ENGINEERING, the Interpretation and Writing of Engineering-Commercial Agreements. By J. I. Tucker. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 341 p., tables, 10x6 in., cloth, $4.00. The principles of law which are common to all branches of legal procedure, and their applications in engineering and business affairs, especially in relation to contracts.

ELECTRIC ELEVATORS, Their Design, Construction, Operation, and Maintenance. By F. A. Annett. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 495 p., illus., 9x6 in., cloth, $5.00. The design and construction of various types of elevators and equipment, and sound methods of inspection, maintenance, and repair, presented in a practical way. Includes new developments in cars, control and signal systems, and automatic landing.

ELECTROMAGNETISM. By H. M. Macdonald. Lond., G. Bell & Sons, Ltd., 1934. 178 p., tables, 9x6 in., cloth, 12s 6d. Develops a consistent scheme for the representation of electrical phenomena from the fundamental laws of electromagnetism, and the derivation of the more immediate consequences of these laws.

ELEKTROTECHNIK, Bd. 2, Pts. 3 and 4. Gleich und Wechselstrommaschinen. By G. Bolz, F. Moeller, and T. Werr. Leipzig and Berlin, B. G. Teubner, 1935. 125 p., illus., 10x7 in., cloth, 10 rm. An introduction to electrical engineering intended for engineers in general, as well as specialists.

ELEMENTS of STRENGTH of MATERIALS. By S. Timoshenko and G. H. MacCullough. N. Y., D. Van Nostrand Co., 1935. 350 p., illus., 9x6 in., cloth, $3.25. An abridgment of Timoshenko's "Strength of Materials," designed primarily as a textbook for undergraduate courses in engineering schools.

ENERGIEÜBERTRAGUNG und-UMWANDLUNG mit WECHSELSTROM, einheitliche Theorie der Leitungen, Transformatoren und Maschinen. By P. Werners. Leipzig and Berlin, B. G. Teubner, 1935. 204 p., illus., 10x6 in., cloth, 18 rm. The fundamentals of a-c theory presented in a uniform way, using the basic concept of the quadripole.

ENGINEERING SHOP PRACTICE, Vol. 2. By O. W. Boston. N. Y., John Wiley & Sons, 1935. 485 p., illus., 9x6 in., cloth, $5.00. Continuation of the description of the basic processes of metal working given in volume one by consideration of production machines.

Les FILTRES ÉLECTRIQUES, Théorie, Construction, Applications. By P. David. 2 ed. Paris, Gauthier-Villars, 1935. 211 p., illus., 10x7 in., paper 50 frs. The general theory of electric wave filters and fundamental equations, with results grouped to permit practical use, and examples of applications.

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Cleveland	2	C. W. Fick	F. E. Harrell	1088 Ivanhoe Rd., Cleveland, Ohio
Columbus	2			
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Ithaca	1	B. K. Northrop	L. A. Burckmyer, Jr	Cornell University, Ithaca, N. Y.
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Lehigh Valley	2	O. A. Griesemer	Edgar Bell	Pennsylvania Pwr. & Lt. Co., Hazleton, Pa.
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Pittsburgh	2	C. A. Powel	J. R. MacGregor	Bell Tel. Co. of Pa., 416—7th Ave., Pittsburgh, Pa.
Pittsfield	1	G. W. Wade	J. R. Meador	General Electric Co., 100 Woodlawn Ave., Pittsfield, Mass.
Portland	9	John Bankus	S. E. Caldwell	Northwestern Elec. Co., Public Service Bldg., Portland, Ore.
Providence	1	P. W. Brouwers	R. J. Underwood	Narragansett Electric Co., Providence, R. I.
Rochester	1	E. K. Huntington	L. R. Gillespie	Rochester Telephone Co., Rochester, N. Y.
St. Louis	7	O. J. Rotty	B. T. McCormick	Wagner Elec. Corp., 6400 Plymouth Ave., St. Louis, Mo.
San Antonio	7	R. J. Foley	M. H. Lovelady	Central Pwr. & Lt. Co., P. O. Box 1116, San Antonio, Texas
San Francisco	8	E. M. Wright	H. S. Lane	Pacific Gas & Elec. Co., 245 Market St., San Francisco, Calif.
Saskatchewan	10	H. I. Nicholl	F. E. Estlin	Canadian General Elec. Co. Ltd., 1809 Cornwall St., Regina, Sask., Can.
Schenectady	1	H. H. Race	Alan Howard	General Electric Co., Engg. Genl. Dept., Schenectady, N. Y.
Seattle	9	L. B. Robinson	E. B. Hansen	820 Fairview North, Seattle, Wash.
Sharon	2	W. A. Sumner	J. H. Chiles, Jr	Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Spokane	9	C. E. Cannon	H. A. Stingle	1412 E. 15th Ave., Spokane, Wash.
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Vancouver	10	Douglas Robertson	J. E. Underhill	B. C. Elec. Railway Co. Ltd., 425 Carrall St., Vancouver, B. C., Can.
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Washington	2	H. L. Curtis	R. B. Stewart	National Press Bldg., Washington, D. C.
Worcester	1	R. P. Bullen	T. R. Holton	22 Shirley St., Auburn, Mass.
Total 61				

Geographical District Executive Committees

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No. 3—New York City	R. H. Tapscott, 4 Irving Place, New York, N. Y.	C. R. Jones, Westinghouse Elec. & Mfg. Co., 30 Rockefeller Plaza, New York, N. Y.
No. 4—Southern	Mark Eldredge, Memphis Power & Light Co., Memphis, Tenn.	R. F. Crenshaw, P. O. Box 439, Memphis, Tenn.
No. 5—Great Lakes	G. G. Post, 314 Public Service Bldg., Milwaukee, Wis.	A. G. Dewars, Northern States Pr. Co., 15 S. 5th St., Minneapolis, Minn.
No. 6—North Central	R. H. Fair, Northwestern Bell Telephone Co., Omaha, Neb.	T. H. Granfield, Northwestern Bell Telephone Co., Omaha, Neb.
No. 7—South West	F. J. Meyer, Oklahoma Gas & Electric Co., Oklahoma City, Okla.	C. W. Mier, Southwestern Bell Tel. Co., 405 N. Broadway, Oklahoma City, Okla.
No. 8—Pacific	N. B. Hinson, Southern Calif. Edison Co. Ltd., Edison Bldg., Los Angeles, Calif.	Fred Garrison, General Elec. Co., 5201 Santa Fe Ave., Los Angeles, Calif.
No. 9—North West	F. O. McMillan, Oregon State College, Corvallis, Ore.	V. B. Wilfley, 901 Porter Bldg., Portland, Ore.
No. 10—Canada	C. V. Christie, McGill University, Montreal, Que.	J. M. Thomson, Ferranti Elec. Ltd., Mount Dennis, Toronto 9, Ont.

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Name and Location	District	Counselor
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Arizona, Univ. of, Tucson, Ariz	8	J. C. Clark
Arkansas, Univ. of, Fayetteville, Ark	7	W. B. Stelzner
Armour Inst. of Tech., Chicago, Ill	5	E. H. Freeman
British Columbia, Univ. of, Vancouver, B. C	10	W. B. Coulthard
Brooklyn, Poly. Inst. of, Brooklyn, N. Y	3	C. C. Whipple
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Bucknell Univ., Lewisburg, Pa	2	G. A. Irland
Calif. Inst. of Tech., Pasadena, Calif	8	R. W. Sorensen
Calif., Univ. of, Berkeley, Calif	8	W. A. Hillebrand
Carnegie Inst. of Tech., Pittsburgh, Pa	2	G. McC. Porter
Case Sch. of Ap. Science, Cleveland, Ohio	2	A. C. Seletzky
Catholic Univ. of America, Washington, D. C	2	T. J. MacKavanagh
Cincinnati, Univ. of, Cincinnati, Ohio	2	L. R. Culver
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Colorado State Agri. Col., Fort Collins, Colo	6	H. G. Jordan
Colorado, Univ. of, Boulder, Colo	6	W. C. DuVall
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New York Univ., New York, N. Y	3	H. N. Walker
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Wyoming, Univ. of, Laramie, Wyo	6	G. H. Sechrist
Yale Univ., New Haven, Conn	1	W. B. Hall
Total 117		

Industrial Notes

Record Size Electrical Equipment for Los Angeles.—Two of the world's largest hydrogen-cooled synchronous condensers will be built by the General Electric Co. for the bureau of power and light, City of Los Angeles, to be installed on the receiving end of the 270-mile transmission line from Boulder Dam. These machines will be rated at 60,000 kva, 13,800 volts, 60 cycles. The installation will be an example of one of the standard applications for synchronous condensers where they perform the function of controlling the power factor of the load so that regulation and losses of the line can be held within reasonable values, thereby controlling within limits the voltage of the receiving bus. Hydrogen cooling results in materially reducing windage losses with a corresponding saving in operating expense. The machines will be installed outdoors.

A 60,000-kva hydrogen-cooled frequency converter has also been ordered from the Westinghouse Electric & Mfg. Co. Rated at a capacity far greater than any previously built, the set will be used for interchanging power between the bureau of power and light and the Southern California Edison Co. and will be located at Wilmington, Calif. Initially, the 50 cycle end will be connected directly to a 50,000-kw steam turbine in the Long Beach plant of the Southern California Edison Co., approximately 4 miles distant. This turbine has been assigned to the city for standby service. Later, when the need for such standby service no longer exists, it is the intention to split the frequency changer into 2 units to be used as 60 cycle synchronous condensers on the Los Angeles end of the transmission line from Boulder Dam. The unit will weigh 600 tons and will be fully enclosed for outdoor service.

Locomotive Plant Nears Completion.—The construction of the Electro-Motive Corp. plant at McCook, Ill., will be completed about September 15, according to a recent announcement from the builders, The Austin Company. The Electro-Motive Corp., a subsidiary of General Motors Corporation, will manufacture Diesel-electric locomotives, principally for railroads. Orders involving more than $3,000,000 are already in hand. In the erection of the plant over 2,000 tons of structural steel was electrically welded. Power for the plant will be furnished by one of the latest model Diesel-electric power units designed for locomotive use.

Empire Sheet & Tin Plate Appointment.—George L. Gaalaas has been appointed by the Empire Sheet & Tin Plate Co. of Mansfield, O., as sales engineer of the electrical sheet department. For the past 9 years Mr. Gaalaas served as design and sales engineer and manager of the synchronous motor division of the Ideal Electric Mfg. Co.

Improved Timken Bearings.—Now being applied to Timken bearings as rapidly as the special equipment required can be built and installed is a major improvement in surface finish termed "mirror finish." This new finish is infinitely smoother than the standard finish and, according to the announcement, even though the measurements were made with equipment capable of measuring in terms of a millionth of an inch, it is impossible to find a flaw in the new finished Timken bearing surface. To achieve this remarkable uniformity in bearing surfaces, years of experimental work have been required. The "Profilograph," now used in the Timken plant as a gauge of mirror finished surfaces, consists essentially of a fine diamond point which acts as a tracer or detector, moving over the surface of the specimen. To this is connected an optical system which magnifies the movement of the detector. In order to record even the most minute irregularities in the finely ground surfaces of Timken bearings, it is necessary to apply a vertical magnification of 2,000 times to the system.

Littelfuse Labs. in Larger Quarters.—Due to increased business in radio fuses and fuse mountings, neon potential fuses, indicators and other new products, the Littelfuse Laboratories moved to larger quarters at 4238 Lincoln Ave., Chicago, on Sept. 1.

Trade Literature

Capacitors.—Bulletin GEA-1584C, 8 pp. Describes Pyranol capacitors for improving power-factor on railway signal-power transmission lines. General Electric Co., Schenectady, N. Y.

Eye Shields.—Catalog, 20 pp. Describes industrial head and eye protective equipment; illustrates new and improved products. Chicago Eye Shield Co., 2300 Warren Boulevard, Chicago.

Transformers.—Bulletin 320, 6 pp. Describes power, welding, and furnace transformers for standard and special requirements. Pennsylvania Transformer Co., 1701 Island Ave., N.S., Pittsburgh.

Insulation Testers.—Bulletin 400, 12 pp. Describes Standco insulation testing sets, including an announcement of the new dwarf megohmer which will be available shortly. Herman H. Sticht & Co., 27 Park Place, New York.

Gearmotors.—Bulletin 2203, 4 pp. Describes self-contained speed reducers with integral or attached motors which permit lowspeed drives with high over-all efficiency. Eight types are illustrated. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Wires and Cables.—Bulletin RE-1, 24 pp. Describes conductors more generally used in rural electrification, including copper, bronze, copperweld, composite conductors, etc. Service Entrance and Service Drop Cables.—Bulletin SE2, 16 pp. General Cable Corp., 420 Lexington Ave., New York.

Transformers.—Bulletin 1173, 6 pp. Describes distribution transformers, showing in a unique way both exterior and cutaway interior views of type SB transformers for 2,400 volt and 4,800 volt circuits, and type CB transformers for 6,900 volt circuits and higher. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Electrostatic Voltmeters.—Bulletin, 4 pp. Describes new electrostatic voltmeters in flush, projecting, and portable types. These instruments are suitable for direct connection on either a-c or d-c lines, for readings up to and including 3,500 volts, and are entirely independent of wave form, frequency and temperature. Prices are included. Ferranti Electric, Inc., 130 West 42nd St., New York.

Disconnecting Switches.—Bulletin 35-B. Gives complete data on ratings, dimensions, operating mechanisms, phase spacings, and insulator characteristics of hook operated and group operated disconnecting switches for rural line service up to and including 34.5 kv. Data is also included on steel mounting frames and cross arm hangers. Delta-Star Electric Co., 2400 Block. Fulton Street, Chicago.

V-Belt Drives.—Catalog, 48 pp., and price list. The installation and operation of V-belt drives is discussed and the book has been simplified for use so that any drive can be completely designed and the delivered price determined from this one text. A section on the care of V-belt drives outlines an easy way of checking tensions, and discusses the effect of oil, water, steam, dust, and chemical fumes. The Gates Rubber Co., Denver, Colo.

Cables.—Bulletin GEA-1278B, 28 pp. Describes in detail 4 major improvements on paper-insulated cable—compack-strand conductor, paper insulation applied in graduated layers, treatment with carbon-dioxide gas, and hydrogen-processed lead-sheath. In addition the 4 general types of paper-insulated cable—oil-filled, shielded Type H, nonshielded, and Pyranol—are described in detail. Insulation thicknesses and other data are also included. General Electric Co., Schenectady, N. Y.

Aircraft Instruments.—Catalog, 12 pp. Describes electrical indicators and other electrically actuated instruments designed for aircraft use, including radio compass indicators and other navigation aids, electrical tachometers, panel ammeters, voltmeters and temperature indicators of both resistance and thermocouple type. Details of the Weston synchroscope, designed to reduce vibration by keeping engine speeds in synchronism in multi-engined planes, is another feature of the bulletin. In addition to electrical and mechanical specifications the catalog contains a group of dimensional drawings to facilitate choice and location of instruments on panels. Weston Electrical Instrument Corp., Newark, N. J.